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THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47 St., New York, N.Y. 10017

89-OCN-7

Computer Program for Lithium Hydroxide — Carbon Dioxide Absorption in Underwater Life Support Systems

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ABSTRACT

Lithium hydroxide (LiOH) has been used as a CO_2 absorbent in underwater life support systems and the space industry. The effectiveness of the LiOH-CO_2 reaction is a function of temperature, humidity, composition of incoming gas, method of packing, geometry of canister, granular size and porosity of the absorbent. Laboratory tests are performed to determine the effects of these factors on LiOH bed-CO_2 absorption. The resulting information can be used to establish an analytical model for LiOH absorber design analysis in underwater life support systems. A computer program is presented to design a LiOH absorber in a manned submersible.

INTRODUCTION

Lithium hydroxide has been used as an absorbent to remove carbon dioxide in an enclosed space (1,2,3). Over the years, a considerable number of studies (4,5,6,7,8) were conducted to improve carbon dioxide removal with the use of lithium hydroxide. As lithium hydroxide absorbs carbon dioxide from a gas stream, the chemical reactions between LiOH and CO_2 can be expressed as:

$$H_2O_{(g)} = H_2O_{(l)} \quad (1)$$

$$LiOH_{(s)} + H_2O_{(g)} = LiOH.H_2O_{(s)} \quad (2)$$

$$2\ LiOH.H_2O_{(s)} + CO_{2(g)} = Li_2CO_{3(s)} + 3\ H_2O_{(l,g)} \quad (3)$$

$$2\ LiOH_{(s)} + CO_{2(g)} = Li_2CO_3 + H_2O_{(l,g)} \quad (4)$$

$$LiOH.H_2O_{(s)} + H_2O_{(l,g)} = LiOH_{(solution)} \quad (5)$$

$$2\ LiOH_{(solution)} + CO_{2(g)} = Li_2CO_3 + H_2O_{(l,g)} \quad (6)$$

The effectiveness of the LiOH-CO_2 reaction varies with temperature, humidity, composition of incoming gas, method of packing, geometry of canister, granular size and porosity of the absorbent (9,10,11,12,13). The hydration of LiOH to monohydrate lithium hydroxide is the initial step toward reaction between CO_2 and LiOH. If an insufficient amount of water vapor in the air stream exists, then the small amount of monohydrate lithium hydroxide formed will allow only partial reaction with carbon dioxide. On the other hand, an excessive quantity of water vapor forms a saturated $LiOH.H_2O$ solution. Water film around the LiOH granules hinders the reaction and results in an incomplete absorption between LiOH and CO_2 (9,13). Therefore, a suitable amount of water vapor, which is regulated by temperature and/or relative humidity, is one of the determining factors to achieve an optimal use of LiOH to remove CO_2.

In addition to the water content, other factors such as CO_2 concentration in the gas stream and residence time also control the absorption efficiency of LiOH. A short residence time normally causes an incomplete chemical reaction and the CO_2 absorption capacity of the absorbent is decreased. However, a longer residence time requires a lower scrubbing rate through the scrubber. This results in CO_2 accumulation in the enclosed space when the CO_2 scrubbing rate is lower than the CO_2 production rate. The optimal residence time and scrubbing rate are needed in order to maintain a desirable CO_2 concentration in the enclosed space (8).

Residence time is defined as the time required for a specific volume of gas to travel through the interstitial spaces within the LiOH canister. Scrubbing rate and the volume available for gas flow control residence time. The available volume in the canister is determined by the granular size, weight of granules and method of packing. For the same amount of absorbent, particles with a smaller granular size have a tendency to be packed more densely than those with a larger granular size. Therefore, residence time of the CO_2 molecule in the canister would vary with granular size.

Presented at the Energy-Sources Technology Conference and Exhibition
Houston, Texas — January 22-25, 1989

APPARATUS AND PROCEDURE

A series of laboratory tests were conducted to investigate the effects of environmental and geometric parameters on CO_2 absorption. The parameters studied include the gas flow rate, gas temperature, humidity, scrubber length and diameter, granular size and CO_2 concentration. Figure 1 shows laboratory equipment set-up for this study.

Each experiment was terminated when the exit air stream from the absorbent tube reached 0.51% CO_2. The time when experiments began until 0.51% CO_2 reached in the exit gas is defined as the breakthrough time (t_B). The ratio of breakthrough time (t_B) to theoretical time (t_{TH}) is the efficiency of LiOH absorption capacity. Theoretical time is the time required when the amount of LiOH completely reacted with CO_2. Theoretical time can be expressed as:

$$t_{(TH)} = \frac{1}{2}\left(\frac{W_a}{M_{LiOH}}\right)\left(\frac{R_g T}{P_T}\right)\left(\frac{1}{v_f' C_{in}}\right) \qquad (7)$$

Plots of efficiency vs. flow rate or residence time were used to illustrate the effects of different parameters on the CO_2 absorption (14).

RESULTS AND DISCUSSION

Temperature effects were studied at 40, 26.5, 15 and 5°C with the gas stream at relative humidity greater than 85%. The results are shown in Figure 2. Because the partial pressure of water vapor decreased with temperature decreased, the lower temperature required a longer residence time to achieve the same efficiency as the higher temperature. The optimal residence times were 0.21, 0.34, 0.55 and 2.55 sec. at 40, 26.5, 15 and 5°C, respectively, for each experimental run. The results indicate the optimal residence time increased as temperature decreased.

Figure 3 displays the humidity effects on the CO_2 absorption. When humidity was less than 70%, the optimal residence time was greater than 0.7 seconds. However, the optimal residence time for a gas stream with humidity greater than 70% was found to be only 0.34 seconds. This shows that lower humidity in the gas stream requires longer residence time in order to have higher absorption efficiency. Figure 4 illustrates the residence time effect on length-to-diameter ratios (L/D) for an axial canister. The results show (L/D) ratio had little effect on CO_2 absorption at the same residence time. The effect of LiOH granular size on the absorption efficiency is shown in Figure 5. Two and one half grams of LiOH with different granular sizes of 0.62, 0.47, and 0.32 cm packed in a 1 cm i.d. reaction tube resulted in a bed length of 8.1, 7.1 and 6.5 cm, respectively. Figure 5 shows when residence time was greater than 0.6 seconds, smaller granular size had less efficiency. The CO_2 concentration in the inlet gas stream also affected absorption efficiency. Concentrations of 1.0%, 2.4% and 4.8% CO_2 in the gas stream were studied. Figure 6 that shows when residence time was less than 0.5 seconds, a lower CO_2 concentration had higher absorption efficiency. Because the shorter residence time resulted in higher flow rate, the lower CO_2 concentration had a more complete reaction with LiOH than with the higher concentrations. Based on the resulting absorption characteristic for each factor controlling the LiOH-CO_2 reaction, an analytical model was established to predict the effectiveness of LiOH absorber in underwater life support systems (15).

COMPUTER PROGRAM FOR DETERMINING ABSORBER'S VOLUME AND EQUILIBRIUM SCRUBBING RATE

The empirical data of the LiOH-CO_2 reaction obtained from this study was programmed to determine the absorber's volume and equilibrium scrubbing rate. The flowchart and input parameters have been shown in Tables 1 and 2, respectively. The absorption efficiency of 1% CO_2 of incoming gas stream at 26.5 °C and R.H. greater 85% (saturated) was used as the standard absorption efficiency. Temperature, humidity and CO_2 concentration correlative factors were obtained from subroutine "TEMP", "HUMID" and "CONC", respectively. The overall efficiency, scrubber volume, scrubbing rate and residence time were computed in the main program (see Appendix). A sample illustration using the program to determine the parameters of an absorber is presented. The absorber is to be operated at 26.5°C and 1 atm. for 5 hours with two divers in a manned submersible (volume = 3.14 m^3 and relative humidity > 85%):

```
ENVIRONMENTAL CONDITIONS
TEMPERATURE AT 5, 15, 26.5 OR 40 C; INPUT IT
IF TEMP =  5.0 C, IT = 1 (TYPE 1)
IF TEMP = 15.0 C, IT = 2 (TYPE 2)
IF TEMP = 26.5 C, IT = 3 (TYPE 3)
IF TEMP = 40.0 C, IT = 4 (TYPE 4)
3<CR>
HUMIDITY OF < 10, 30-40, 60-70 OR > 85%; INPUT IH
IF HUMID < 10% (DRY),          IH = 1 (TYPE 1)
IF HUMID = 30-40%,             IH = 2 (TYPE 2)
IF HUMID = 60-70%,             IH = 3 (TYPE 3)
IF HUMID > 85% (SATURATED),    IH = 4 (TYPE 4)
4<CR>
ENTER PARTIAL PRESSURE OF CO2, ATM
IF CONC = 1.0%, TYPE 0.01
IF CONC = 2.4%, TYPE 0.024
IF CONC = 4.8%, TYPE 0.048
0.01<CR>
PRESSURE, ATM
1<CR>
HOW MANY PERSONS ARE IN THE CHAMBER?
2<CR>
HOW MANY HOURS ARE REQUIRED?
5<CR>
CO2 PRODUCTION RATE, GRAM/HOUR/PERSON
52<CR>
RATIO OF SCRUBBER LENGTH TO DIAMETER
3.6<CR>

 ENVIRONMENTAL CONDITIONS
 TEMPERATURE =     26.5000      C
 PRESSURE =     1.00000      ATM
 MAX. ALLOWABLE CO2 MOLAR FRACTION =     1.000000E-02
 HUMIDITY > 85% (SATURATED)
 PERSON =     2.00000
 TIME =     5.00000      HOUR

 DESIGN CRITERIA
 NO. OF ITERATION =          1
 SCRUBBER VOLUME =  1614.00      CC
 LENGTH =  29.8647      CM
 DIAMETER =  8.29522      CM
 VELOCITY =  29.8543      CM/SEC
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 AMOUNT OF LIOH PACKED =  743.410     G
 SCRUBBER FLOW RATE =  1613.44     CC/SEC
 RESIDENCE TIME (LAST-1) = 0.653870     SEC
 RESIDENCE TIME (LAST) = 0.650226     SEC
 OVERALL EFFICIENCY = 0.760303

END OF COMPUTATION
****STOP
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ACKNOWLEDGMENTS

The authors wish to thank the Link Foundation for partially supporting this study. Thanks also to Mr. D. Boryta for technical discussion and Ms. Debbie Farb for typing the manuscript. This paper is Harbor Branch Contribution No. 702.

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APPENDIX

```
      PROGRAM SCRUBBER
      REAL PERSON,HOUR,T,P,CO2,RTNEW,RCO2,LENGTH
      INTEGER IT,IH,IC
      OPEN (UNIT=6,FILE='TAEM',STATUS='NEW')
      OPEN (UNIT=7,FILE='SOUT',STATUS='NEW')
******INPUT DATA INTERACTIVELY
      WRITE (1,*) 'ENVIRONMENTAL CONDITIONS'
      WRITE (1,*) 'TEMPERATURE AT 5, 15, 26.5 OR 40 C;
INPUT IT'
      WRITE (1,*) 'IF TEMP =  5.0 C, IT = 1 (TYPE 1)'
      WRITE (1,*) 'IF TEMP = 15.0 C, IT = 2 (TYPE 2)'
      WRITE (1,*) 'IF TEMP = 26.5 C, IT = 3 (TYPE 3)'
      WRITE (1,*) 'IF TEMP = 40.0 C, IT = 4 (TYPE 4)'
      READ (1,*) IT
      IF (IT .EQ. 1) T = 5.0
      IF (IT .EQ. 2) T = 15.0
      IF (IT .EQ. 3) T = 26.5
      IF (IT .EQ. 4) T = 40.0
      WRITE (1,*) 'HUMIDITY OF < 10, 30-40, 60-70 OR >
         85%; INPUT IH'
      WRITE (1,*) 'IF HUMID < 10% (DRY),       IH = 1
         (TYPE 1)'
      WRITE (1,*) 'IF HUMID = 30-40%,          IH = 2
         (TYPE 2)'
      WRITE (1,*) 'IF HUMID = 60-70%,          IH = 3
         (TYPE 3)'
      WRITE (1,*) 'IF HUMID > 85% (SATURATED), IH = 4
         (TYPE 4)'
      READ (1,*) IH
      WRITE (1,*) 'ENTER PARTIAL PRESSURE OF CO2, ATM'
      WRITE (1,*) 'IF CONC = 1.0%, TYPE 0.01'
      WRITE (1,*) 'IF CONC = 2.4%, TYPE 0.024'
      WRITE (1,*) 'IF CONC = 4.8%, TYPE 0.048'
      READ (1,*) CO2
      IF (CO2 .LE. 0.017) IC = 1
      IF ((CO2 .GT. 0.017) .AND. (CO2 .LE. 0.036)) IC
         = 2
      IF (CO2 .GT. 0.036) IC = 3
      WRITE (1,*) 'PRESSURE, ATM'
      READ (1,*) P
      WRITE (1,*) 'HOW MANY PERSONS ARE IN THE
         CHAMBER?'
      READ (1,*) PERSON
      WRITE (1,*) 'HOW MANY HOURS ARE REQUIRED?'
      READ (1,*) HOUR
        WRITE (1,*) 'CO2 PRODUCTION RATE,
GRAM/HOUR/PERSON'
      WRITE (1,*) 'FOR NORMAL CONDITION, SUGGESTED
         VALUE = 52'
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      READ (1,*) RCO2
      WRITE (1,*) 'RATIO OF SCRUBBER LENGTH TO
         DIAMETER'
      READ (1,*) RLD
      WRITE (1,*) 'TO ENTER DESIRED LENGTH AND
         DIAMETER, TYPE 1'
      WRITE (1,*) 'OR TYPE 2 FOR COMPUTER GENERATED
         VALUES'
      READ  (1,*) ILD
      IF (ILD .EQ. 2) GO TO 5
      WRITE (1,*) 'INPUT DIAMETER AND LENGTH (CM)'
      READ (1,*) D,LENGTH
    5 WRITE (1,*) 'VOLUMETRIC FLOW RATE, CM/SEC'
      READ (1,*) VF
      WRITE (1,*) 'TO ENTER GRAMS LIOH PACKED, TYPE 1'
      WRITE (1,*) 'OR TYPE 2 FOR COMPUTER GENERATED
         VALUES'
      READ (1,*) IG
      IF (IG .EQ. 2) GO TO 6
      WRITE (1,*) 'ENTER LIOH PACKED (GRAM)'
      READ (1,*) TOTLIOH
    6 RTO = 0.19
*****INITIALIZATION
      IRT = 0
      SAFE = 0.85
      VOID = 0.65
      DLIOH = 1.316
      DCO2 = P/0.08205/(T+273)*44.0
*****BEGINNING OF A NEW RESIDENCE TIME
   10 RTO = RTO + 0.01
      RTNEW = RTO
      IRT = IRT + 1
      ICOUNT = 0
*****ITERATION
   20 RT = RTNEW
      ICOUNT = ICOUNT + 1
*****STANDARD EFFICIENCY AT 26.5 C, R.H. 85%, 1% OF
         CO2
      IF (RT .LT. 0.182) GO TO 11
      IF ((RT .GE. 0.182) .AND. (RT .LT. 0.198)) GO TO
         12
      IF ((RT .GE. 0.198) .AND. (RT .LT. 0.219)) GO TO
         13
      IF ((RT .GE. 0.219) .AND. (RT .LT. 0.282)) GO TO
         14
      IF ((RT .GE. 0.282) .AND. (RT .LT. 0.336)) GO TO
         15
      IF ((RT .GE. 0.336) .AND. (RT .LT. 0.522)) GO TO
         16
      IF ((RT .GE. 0.522) .AND. (RT .LT. 1.088)) GO TO
         17
      IF ((RT .GE. 1.088) .AND. (RT .LT. 3.161)) GO TO
         18
      EFF = 0.573
      GO TO 100
   11 EFF = 0.123
      GO TO 100
   12 EFF = 0.123 + 1.5625000*(RT-0.182)
      GO TO 100
   13 EFF = 0.148 +26.7619040*(RT-0.198)
      GO TO 100
   14 EFF = 0.710 + 2.0793650*(RT-0.219)
      GO TO 100
   15 EFF = 0.841 + 1.0000000*(RT-0.282)
      GO TO 100
   16 EFF = 0.895 - 0.5913978*(RT-0.336)
      GO TO 100
   17 EFF = 0.785 - 0.1872791*(RT-0.522)
      GO TO 100
   18 EFF = 0.679 - 0.0511336*(RT-1.088)
  100 EFFSTD = EFF
*****CALL SUBROUTINE HUMID, TEMP, CONC
      CALL HUMID (IH,EFFSTD,RT,EFFH)
      CALL TEMP (IT,EFFSTD,RT,EFFT)
      CALL CONC (IC,EFFSTD,RT,EFFC)
******OVERALL EFFICIENCY
      EFFALL = EFFH*EFFT*EFFC*EFFSTD
      IF (EFFALL .GT. 1.E-10) GO TO 150
      WRITE(1,*) 'OVERALL EFFICIENCY = 0'
      GO TO 200
******COMPUTE MINIMUM CANISTER VOLUME
  150 TOTCO2 = RCO2*PERSON*HOUR
      IF (IG .EQ. 1) GO TO 155
      TOTLIOH = TOTCO2/0.92/EFFALL
  155 IF (ILD .EQ. 1) GO TO 160
      VOL = TOTLIOH/DLIOH/(1.0-VOID)
      GO TO 170
  160 VOL = 3.1416*D*D/4.*LENGHTH
******COMPUTE SCRUBBER FLOW RATE
*     VF =, RCO2*PERSON/(CO2*SAFE -0.005)/DCO2*1000.
         /3600.
******COMPUTE NEW RESIDENCE TIME FROM CANISTER VOLUME
         AND FLOW RATE
  170 RTNEW = VOL*VOID/VF
******IF NO OF ITERATIONS > 5, STOP
      IF (ICOUNT .GT. 5) GO TO 200
******IF DIFFERENCE BETWEEN NEW AND OLD RESIDENCE TIME
         < 1% OF OLD
******RESIDENCE TIME, STOP; OTHERWISE, CONTINUE
      DIFF = ABS (RTNEW - RT)
      CHECK = DIFF/RT
      IF (DIFF .GT. 0.01) GO TO 20
******IF IT CAN'T BE CONVERGED WITHIN 5 TRIALS, THEN
         TRY A NEW GUESS RT
******BY INCREMENT OF 0.01 SEC
  200 IF ((IRT .LT. 180) .AND. (ICOUNT .GT. 5)) GO TO
         10
******COMPUTE SCRUBBER LENGTH, DIAMETER AND VELOCITY
      IF (ILD .EQ. 1) GO TO 210
      D = (VOL*4.0/RLD/3.1416)**(0.33333)
      LENGTH = VOL*4.0/3.1416/D/D
  210 U = VF*4.0/3.1416/D/D
******PRINT THE FINAL RESULTS
      WRITE (1,*) ' ENVIRONMENTAL CONDITIONS'
      WRITE (1,*) ' TEMPERATURE = ',T,'  C'
      WRITE (1,*) ' PRESSURE = ',P,'  ATM'
      WRITE (1,*) ' MAX. ALLOWABLE CO2 MOLAR FRACTION
         = ',CO2
      WRITE (7,*) ' ENVIRONMENTAL CONDITIONS'
      WRITE (7,*) ' TEMPERATURE = ',T,'  C'
      WRITE (7,*) ' PRESSURE = ',P,'  ATM'
      WRITE (7,*) ' MAX. ALLOWABLE CO2 MOLAR FRACTION
         = ',CO2
      IF (IH .NE. 1) GO TO 240
      WRITE (1,*) ' HUMIDITY < 10% (DRY)'
      WRITE (7,*) ' HUMIDITY < 10% (DRY)'
      GO TO 270
  240 IF (IH .NE. 2) GO TO 250
      WRITE (1,*) ' HUMIDITY = 30-40%'
      WRITE (7,*) ' HUMIDITY = 30-40%'
      GO TO 270
  250 IF (IH .NE. 3) GO TO 260
      WRITE (1,*) ' HUMIDITY = 60-70%'
      WRITE (7,*) ' HUMIDITY = 60-70%'
      GO TO 270
  260 WRITE (1,*) ' HUMIDITY > 85% (SATURATED)'
      WRITE (7,*) ' HUMIDITY > 85% (SATURATED)'
  270 WRITE (1,*) ' PERSON = ',PERSON
      WRITE (1,*) ' TIME = ',HOUR,'  HOUR'
      WRITE (1,275)
      WRITE (1,*) ' DESIGN CRITERIA'
      WRITE (1,*) ' NO. OF ITERATION = ',IRT
      WRITE (1,300) VOL,LENGTH,D,U
      WRITE (1,350) TOTLIOH,VF,RT,RTNEW,EFFALL
  275 FORMAT (/)
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```
300 FORMAT (2X,'SCRUBBER VOLUME = ',G12.6,'
       CC',/,2X,'LENGTH = ',
   1 G12.6,'  CM',/,2X,'DIAMETER = ',G12.6,'
       CM',/,2X,'VELOCITY = ',
   2 G12.6,'  CM/SEC')
350 FORMAT (2X,'AMOUNT OF LIOH PACKED = ',G12.6,'
       G',/,2X,
   2 'SCRUBBER FLOW RATE = ',G12.6,'CC/SEC',/,2X,'
       RESIDENCE TIME (LAS
   3T-1) = ',G12.6,' SEC',/,2X,'RESIDENCE TIME
       (LAST) = ',G12.6,
   4 ' SEC',/,2X,'OVERALL EFFICIENCY = ',G12.6)
    WRITE (7,*) ' PERSON = ',PERSON
    WRITE (7,*) ' TIME = ',HOUR,'  HOUR'
    WRITE (7,275)
    WRITE (7,*) ' DESIGN CRITERIA'
    WRITE (7,*) ' NO. OF ITERATION = ',IRT
    WRITE (7,300) VOL,LENGTH,D,U
    WRITE (7,350) TOTLIOH,VF,RT,RTNEW,EFFALL
    WRITE (1,275)
    WRITE (1,*) 'END OF COMPUTATION'
    WRITE (6,*) LENGTH,U,D,VF
    WRITE (6,*) TOTLIOH,P,HOUR,PERSON,RCO2
    WRITE (6,*) IC,IH,IT
    STOP
    END
****************************************************
****SUBROUTINE HUMIDITY
    SUBROUTINE HUMID (IH,EFFSTD,RT,EFFH)
    IF (IH .EQ. 1) GO TO 10
    IF (IH .EQ. 2) GO TO 20
    IF (IH .EQ. 3) GO TO 30
    IF (IH .EQ. 4) GO TO 40
****HUMIDITY LESS THAN 10%
 10 IF (RT .LT. 0.169) GO TO 11
    IF ((RT .GE. 0.169) .AND. (RT .LT. 0.335)) GO TO
       12
    IF ((RT .GE. 0.335) .AND. (RT .LT. 1.027)) GO TO
       13
    IF ((RT .GE. 1.027) .AND. (RT .LT. 2.992)) GO TO
       14
    EFF = 1.0
    GO TO 100
 11 EFF = 0.207
    GO TO 100
 12 EFF = 0.207 + 2.2771084*(RT-0.169)
    GO TO 100
 13 EFF = 0.585 + 0.4638728*(RT-0.335)
    GO TO 100
 14 EFF = 0.906 + 0.0478371*(RT-1.027)
    GO TO 100
****HUMIDITY 30-40%
 20 IF (RT .LT. 0.160) GO TO 21
    IF ((RT .GE. 0.160) .AND. (RT .LT. 0.236)) GO TO
       22
    IF ((RT .GE. 0.236) .AND. (RT .LT. 0.705)) GO TO
       23
    IF ((RT .GE. 0.705) .AND. (RT .LT. 1.197)) GO TO
       24
    EFF = 0.974
    GO TO 100
 21 EFF = 0.183
    GO TO 100
 22 EFF = 0.183 + 2.1052631*(RT-0.160)
    GO TO 100
 23 EFF = 0.343 + 1.2153518*(RT-0.236)
    GO TO 100
 24 EFF = 0.913 + 0.1239837*(RT-0.705)
    GO TO 100
****HUMIDITY 60-70%
 30 IF (RT .LT. 0.145) GO TO 31
    IF ((RT .GE. 0.145) .AND. (RT .LT. 0.257)) GO TO
       32
    IF ((RT .GE. 0.257) .AND. (RT .LT. 0.323)) GO TO
       33
    IF ((RT .GE. 0.323) .AND. (RT .LT. 0.912)) GO TO
       34
    EFF = 0.804
    GO TO 100
 31 EFF = 0.098
    GO TO 100
 32 EFF = 0.098 + 1.9642857*(RT-0.145)
    GO TO 100
 33 EFF = 0.318 + 3.5909090*(RT-0.257)
    GO TO 100
 34 EFF = 0.555 + 0.4227504*(RT-0.323)
    GO TO 100
****HUMIDITY GREATER THAN 85%
 40 EFF = EFFSTD
****
100 IF (EFF .LT. 1.0E-10) WRITE (1,*) 'EFFICIENCY
       (HUMID) = 0'
    EFFH = EFF/EFFSTD
    RETURN
    END
****************************************************
****SUBROUTINE TEMPERATURE
    SUBROUTINE TEMP (IT,EFFSTD,RT,EFFT)
    IF (IT .EQ. 1) GO TO 10
    IF (IT .EQ. 2) GO TO 20
    IF (IT .EQ. 3) GO TO 30
    IF (IT .EQ. 4) GO TO 40
****TEMPERATURE AT 5 C
 10 IF (RT .LT. 0.164) GO TO 11
    IF ((RT .GE. 0.164) .AND. (RT .LT. 0.405)) GO TO
       12
    IF ((RT .GE. 0.405) .AND. (RT .LT. 0.838)) GO TO
       13
    IF ((RT .GE. 0.838) .AND. (RT .LT. 2.551)) GO TO
       14
    EFF = 0.824
    GO TO 100
 11 EFF = 0.066
    GO TO 100
 12 EFF = 0.066 + 2.2074688*(RT-0.164)
    GO TO 100
 13 EFF = 0.598 + 0.4826789*(RT-0.405)
    GO TO 100
 14 EFF = 0.807 + 0.0099241*(RT-0.838)
    GO TO 100
****TEMPERATURE AT 15 C
 20 IF (RT .LT. 0.140) GO TO 21
    IF ((RT .GE. 0.140) .AND. (RT .LT. 0.364)) GO TO
       22
    IF ((RT .GE. 0.364) .AND. (RT .LT. 1.035)) GO TO
       23
    EFF = 0.880
    GO TO 100
 21 EFF = 0.088
    GO TO 100
 22 EFF = 0.088 + 3.5848214*(RT-0.140)
    GO TO 100
 23 EFF = 0.891 - 0.0163934*(RT-0.364)
    GO TO 100
****TEMPERATURE AT 26.5 C
 30 EFF = EFFSTD
    GO TO 100
****TEMPERATURE AT 40 C
 40 IF (RT .LT. 0.153) GO TO 41
    IF ((RT .GE. 0.153) .AND. (RT .LT. 0.207)) GO TO
       42
    IF ((RT .GE. 0.207) .AND. (RT .LT. 0.560)) GO TO
       43
    IF ((RT .GE. 0.560) .AND. (RT .LT. 2.482)) GO TO
       44
    EFF = 0.354
```

```
      GO TO 100
   41 EFF = 0.688
      GO TO 100
   42 EFF = 0.688 + 0.0944444*(RT-0.153)
      GO TO 100
   43 EFF = 0.739 + 0.6968838*(RT-0.207)
      GO TO 100
   44 EFF = 0.493 + 0.0732040*(RT-0.560)
******
  100 IF (EFF .LT. 1.0E-10) WRITE (1,*) 'EFFICIENCY
         (TEMP) = 0'
      EFFT = EFF/EFFSTD
      RETURN
      END
***********************************************************
******SUBROUTINE CONCENTRATION
      SUBROUTINE CONC (IC,EFFSTD,RT,EFFC)
      IF (IC .EQ. 1) GO TO 10
      IF (IC .EQ. 2) GO TO 20
      IF (IC .EQ. 3) GO TO 30
******CONCENTRATION OF 1%
   10 EFF = EFFSTD
      GO TO 100
******CONCENTRATION OF 2.4%
   20 IF (RT .LT. 0.169) GO TO 21
      IF ((RT .GE. 0.169) .AND. (RT .LT. 0.299)) GO TO
         22
      IF ((RT .GE. 0.299) .AND. (RT .LT. 0.553)) GO TO
         23
      IF ((RT .GE. 0.553) .AND. (RT .LT. 0.856)) GO TO
         24
      IF ((RT .GE. 0.856) .AND. (RT .LT. 3.154)) GO TO
         25
      EFF = 0.739
      GO TO 100
   21 EFF = 0.088
      GO TO 100
   22 EFF = 0.088 + 0.2615384*(RT-0.169)
      GO TO 100
   23 EFF = 0.122 + 1.3661417*(RT-0.299)
      GO TO 100
   24 EFF = 0.469 + 0.6633663*(RT-0.553)
      GO TO 100
   25 EFF = 0.670 + 0.0300261*(RT-0.856)
      GO TO 100
******CONCENTRATION OF 4.8%
   30 IF (RT .LT. 0.169) GO TO 31
      IF ((RT .GE. 0.169) .AND. (RT .LT. 1.698)) GO TO
         32
      IF ((RT .GE. 1.698) .AND. (RT .LT. 3.123)) GO TO
         33
      EFF = 0.783
      GO TO 100
   31 EFF = 0.097
      GO TO 100
   32 EFF = 0.097 + 0.3629823*(RT-0.169)
      GO TO 100
   33 EFF = 0.652 + 0.0919298*(RT-1.698)
******
  100 IF (EFF .LT. 1.0E-10) WRITE (1,*) 'EFFICIENCY
(CONE) = 0'
      EFFC = EFF/EFFSTD
      RETURN
      END
```

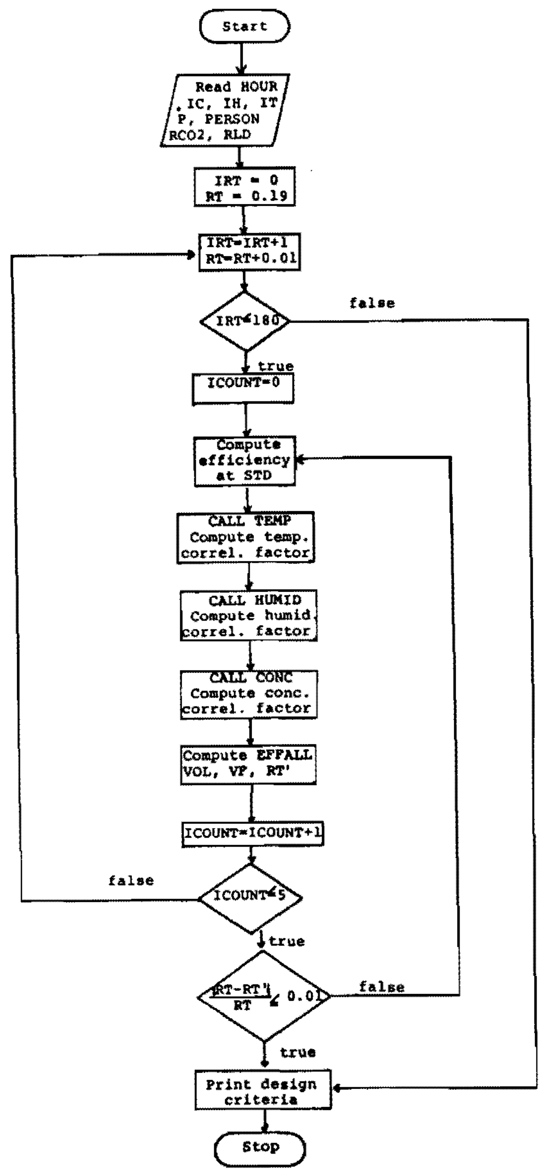

Table 1. Flowchart "Scrubber"

Table 2. Input Parameters of "SCRUBBER" Program.

Parameter	Description	
CO2	partial pressure of CO_2, atm	
HOUR	duration period, hour	
IH	relative humidity	
	if humidity < 10% (dry),	IH = 1
	if humidity = 30-40%,	IH = 2
	if humidity = 60-70%,	IH = 3
	if humidity > 85%	IH = 4
IT	temperature	
	if temperature = 5.0 °C,	IT = 1
	if temperature = 15.0 °C,	IT = 2
	if temperature = 26.5 °C,	IT = 3
	if temperature = 40.0 °C,	IT = 4
P	pressure, atm	
PERSON	number of people in the chamber	
RCO2	CO_2 production rate, gram of	
	RCO2 = 52, for normal condition	
RLD	ratio of scrubber length to diameter	

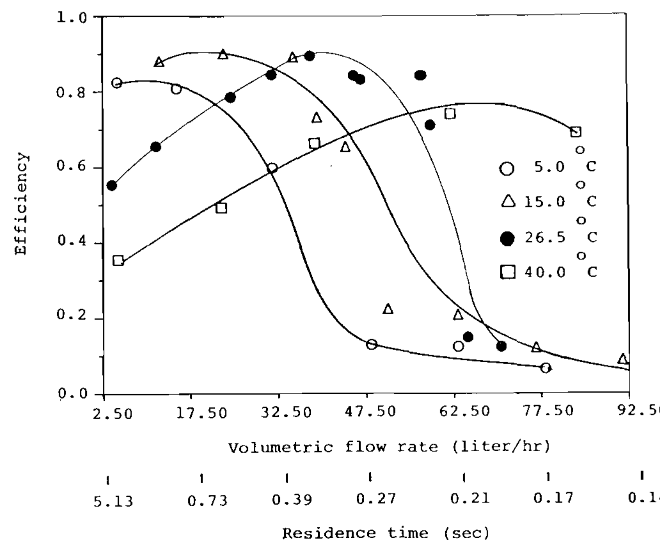

Figure 2. The effects of temperature on LiOH-CO_2 absorption.

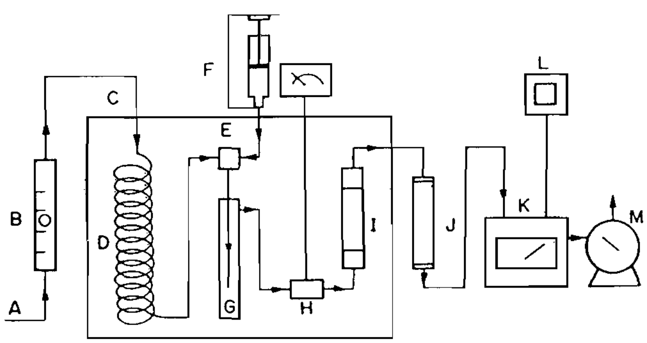

Figure 1. Dynamic gas flow system. A: Inlet air stream; B: Flow meter; C: Temperature controlled water bath; D: Copper coil, 20 ft x 1/8 in; E: Air-water mixer; F: Syringe pump; G: Midget bubbler; H: Temperature and humidity sensor; I: Absorbent tube; J: Drying tube; K: CO_2 detector; L: Strip chart recorder; M: Wet test meter.

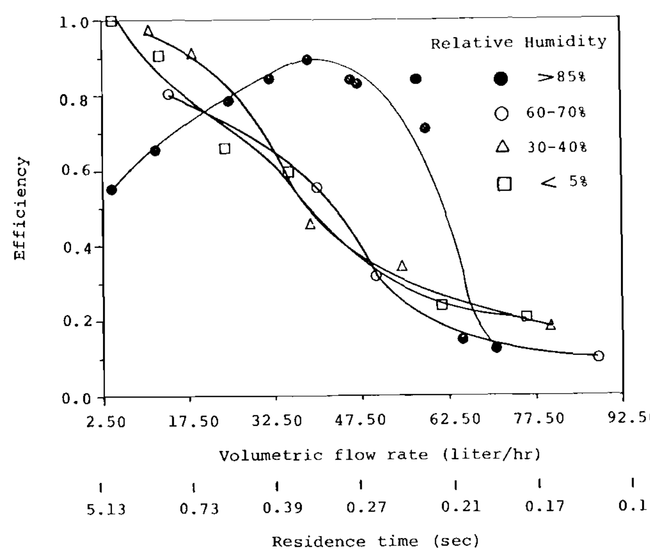

Figure 3. The effects of humidity on the LiOH-CO_2 absorption.

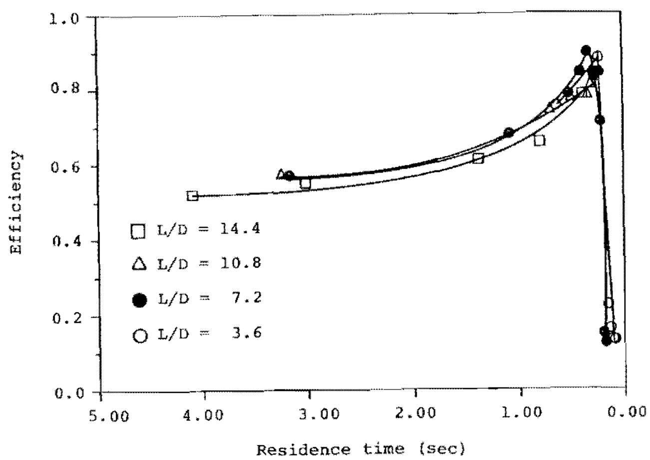

Figure 4. The effects of (L/D) ratio on the $LiOH-CO_2$ absorption.

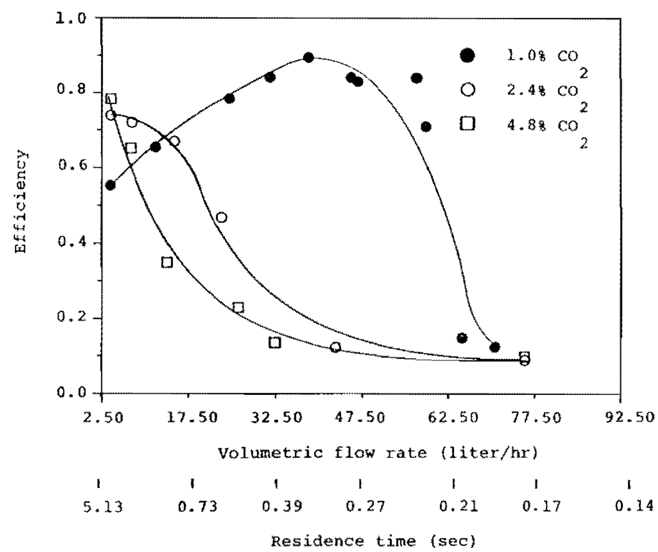

Figure 6. The effects of CO_2 concentration on the $LiOH-CO_2$ absorption.

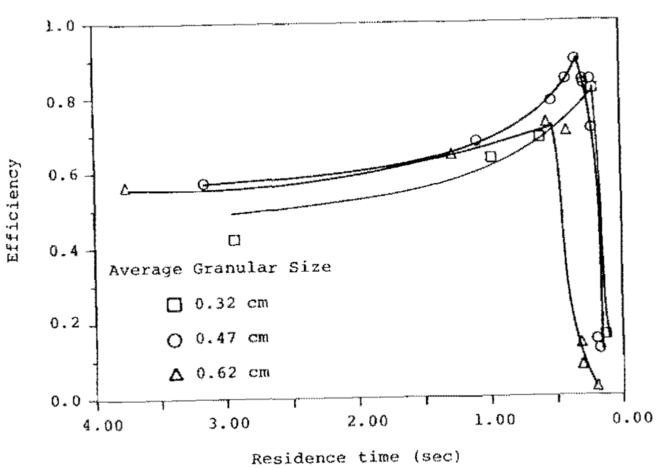

Figure 5. The effects of granular size on the $LiOH-CO_2$ absorption.