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A Mathematical Model for Liquid Flow Transients in a Rotary Dissolver

B. E. Lewis
F. E. Weber

CONSOLIDATED FUEL REPROCESSING PROGRAM

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CONSOLIDATED FUEL REPROCESSING PROGRAM

A MATHEMATICAL MODEL FOR LIQUID FLOW TRANSIENTS IN A ROTARY DISSOLVER

B. E. Lewis and F. E. Weber
Chemical Technology Division

Date Published - October 1980

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HIGHLIGHTS

A model describing the liquid outlet response to perturbations in the flow to a compartmented rotary dissolver has been developed. The model incorporates stagewise differential material balances coupled with the general equation for flow over a weir to calculate acid concentrations and liquid volumes in each stage. Data were taken from step-change flow experiments conducted on a 0.5-t/d rotary dissolver. The predicted response of the model was in good agreement with the data from the dissolver experiments. All constants in the model were obtained by independent tests. The model appears to be applicable over a wide range of dissolver operating conditions; however, temperature fluctuations and the presence of solids were not addressed.

1. INTRODUCTION

The prediction of the effects of perturbations in the flow and concentration of liquid feed to a continuous rotary dissolver is important in several aspects of dissolver process design and control. The initial startup of a continuous dissolver requires that a certain flow and concentration of acid be established before any testing or dissolving can be accomplished effectively. Initiation of the dissolution reactions before the proper acid concentration or flow has been established can lead to acid deficient situations. Also, during normal operations, acid flow and concentration perturbations may cause problems leading to the production of off-specification dissolver products. These problems could be minimized or possibly avoided with an early indication of the effect of flow changes on the acid concentration in each stage of the dissolver. Therefore, a computer code has been developed to model the acid flow and concentration in each stage of the compartmented rotary dissolver for the nitric acid-water system. The code also gives insight into a solution for the more complex unsteady-state material balance model with chemical reaction. This report is concerned with the development and presentation of the results from the computer simulation of the flow and concentration of the nitric acid-water system within the present 0.5-t/d continuous rotary dissolver.

The dissolver is a compartmented device consisting of a 0.75-m-diam drum enclosed in a rectangular shroud. An isometric view of the dissolver drum is shown in Fig. 1. The drum is ~ 2.4-m long and has nine separate stages or compartments. Liquid moves through the dissolver by flowing through the slots in the walls (shown in the cutaway in Fig. 1) separating each stage. Eight of the stages contain nitric acid and one contains only a rinse water-acid solution. The rinse stage is not considered in this analysis. Each stage is ~ 26-cm long and maintains a nominal liquid inventory of ~ 5 ℓ. Each stage contains a single baffle to provide agitation and solids transfer as the drum is rotated; therefore, complete mixing is assumed.

It has been shown in previous experiments on a single-dissolving stage rotary dissolver that the acid concentration in the outlet stream can be approximated by a simple stirred tanks-in-series model.[1] Several variations of stirred tank models were used (with varying degrees of success) in an effort to model the 0.5 t/d dissolver. Initially, the simple single-parameter, tanks-in-series model with constant flow rate and tank volume was used.[2] This model, which is similar to the single-stage model, predicted concentrations that preceded the actual data by as much as ~ 10 min. A variation of this model involving the introduction of a time-lag term into the concentration equation was also used. This alternate model predicted the experimental data very well during the first half of the run but lagged during the latter half. The two models appeared to have deviated from the actual data because of the assumptions of constant flow rates and stage volumes. In order to take into account the variations in flow and volume, it was necessary to start with the differential material balance equation. A schematic diagram showing the flow through the dissolver is presented in Fig. 2. The overflow from the ith tank becomes the feed to the $(i-1)$th tank. The fluid dynamics of the liquid were modeled as flow over a weir, since liquid flows through the slots in the stage walls without completely filling the slots.

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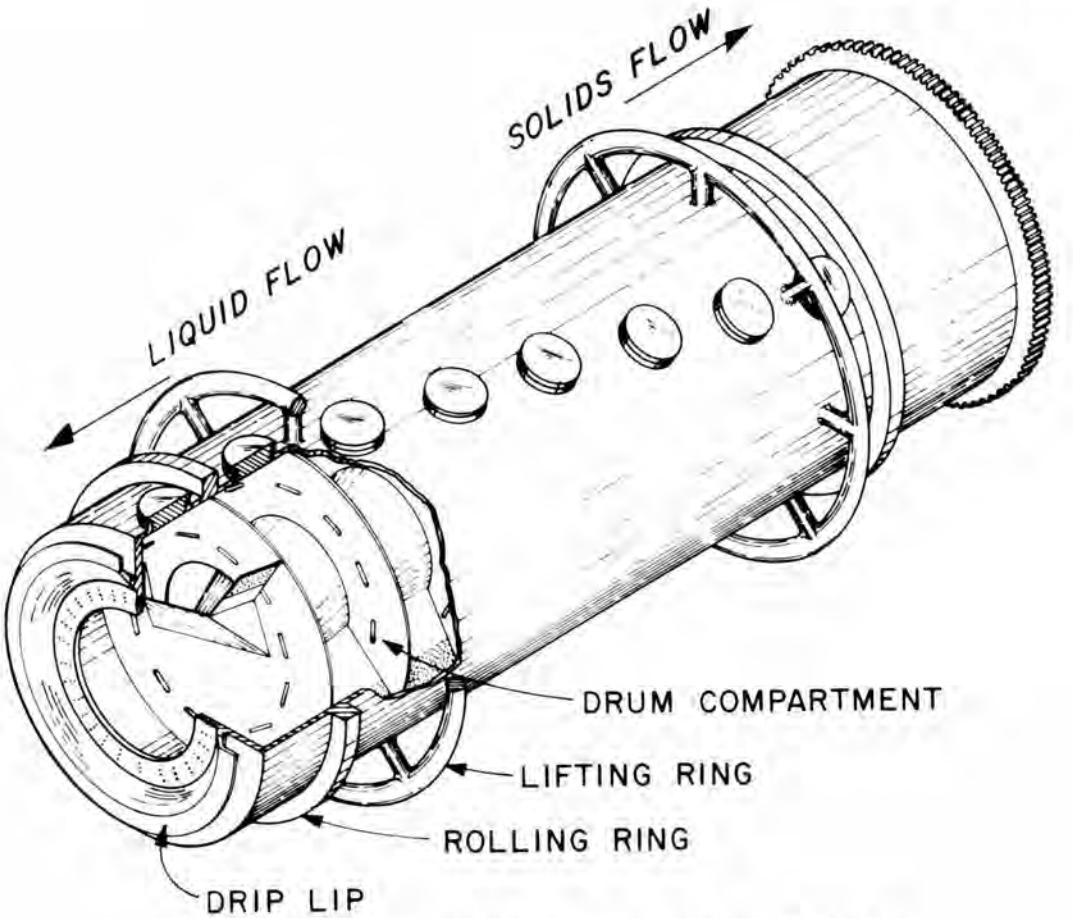

Fig. 1. Cutaway view of the 0.5-t/d compartmented rotary dissolver drum.

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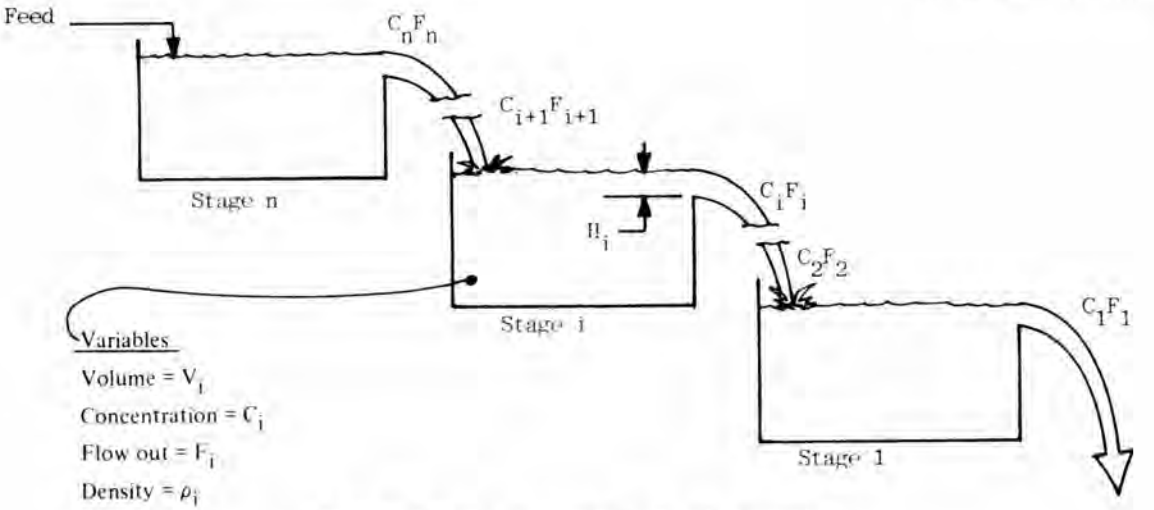

Fig. 2. Schematic representations of model parameters.

2. MATHEMATICAL TREATMENT

Basically, there are four variables in this problem: the volumetric flow rate out of stage $i,(F_i)$; the concentration of acid in stage $i,(C_i)$; the liquid volume of stage $i,(V_i)$; and the liquid density in stage $i,(\rho_i)$. Thus, four equations are necessary to solve for unknowns.

Since we are dealing with a water-acid system, two material balances can be written:

$$\text{Acid:} \quad F_{i+1}C_{i+1} - F_iC_i = \frac{d}{dt}(C_iV_i) \tag{1}$$

$$\text{Total:} \quad \rho_{i+1}F_{i+1} - \rho_iF_i = \frac{d}{dt}(\rho_iV_i) \tag{2}$$

A third equation that could be applied was an empirical relation between concentration and density for nitric acid:

$$\rho_i = f(C_i) \quad . \tag{3}$$

The final equation was from the fluid mechanics of the problem. The general equation describing flow over a weir is given by

$$F = \mathrm{K}H^{\mathrm{P}} \quad , \tag{4}$$

where F is the volumetric flow rate, H is the height of fluid over the weir, and K and P are empirical constants. If V_0 is the volume of stage i up to the bottom of the weir, and A_S is the horizontal surface area of stage i, then the following relation between the liquid volume and the height over the weir holds:

$$V_i = V_0 + A_SH \quad . \tag{5}$$

Combining Eqs. (4) and (5),

$$V_i = V_0 + A_S\left(\frac{F_i}{\mathrm{K}}\right)^{1/\mathrm{P}} \quad . \tag{6}$$

Equations (1), (2), (3), and (6) comprise a closed system of simultaneous nonlinear differential equations, with initial conditions at $t = 0$: $C_i = C_{i,0}$ and $\rho_i = \rho_{i,0}$ for $i = 1,8$.

Before the above set of equations could be solved, the functional relationship between ρ_i and C_i was required. For nitric acid solutions, the density is approximately linear with concentration up to 44% acid. Thus, Eq. (3) could be written as:

$$\rho_i = \mathrm{a} + \mathrm{b}C_i, \tag{7}$$

where the constants a and b were determined by linear regression.

Equations (1) and (2) were solved by a fully implicit finite difference technique. Earlier attempts with an explicit technique led to stability problems. The advantage of unconditional stability with a fully implicit technique was felt to outweigh the increase in computation time.

After application of the finite difference scheme with a time step of Δt and extensive algebraic manipulation, Eqs. (1), (2), (3), and (6) were written as:

$$C_i = \frac{aH_i}{J_i - bH_i} , \tag{8}$$

$$\rho_i = \frac{aJ_i}{J_i - bH_i} , \tag{9}$$

$$F_i = \frac{H_i}{C_i} - (E_i - GF_i^{1/P}) \frac{1}{\Delta t} , \tag{10}$$

$$V_i = E_i + GF_i^{1/P} , \tag{11}$$

where E_i and G depend only on the geometric properties of the dissolver and are given by:

$$E_i = V_0 \tag{12}$$

and

$$G = \frac{A_S}{K^{1/P}} . \tag{13}$$

H_i and J_i depend on the state of the fluid both in the upstream stage and at the previous time step and can be written:

$$H_i = F_{i+1}C_{i+1} + \frac{C_i^0 V_i^0}{\Delta t} , \tag{14}$$

and

$$J_i = \rho_{i+1}F_{i+1} + \frac{\rho_i^0 V_i^0}{\Delta t} , \tag{15}$$

where the superscripts indicate the previous time step.

Equations (8) through (11) and the associated relationships in Eqs. (12) through (15) were required to solve the material balance for each of the eight stages in the 0.5-t/d dissolver. The solution order (Fig. 3) was from stage 8 (the acid-entry stage) to stage 1 (the liquid-outlet stage). Therefore, for stage i, all the information to solve for C_i, ρ_i, F_i, and V_i is known either from previous calculations or from the initial conditions. Because of the nonlinearity of Eq. (10), an iterative solution for F_i was required. The secant method was used since simpler methods, such as successive substitutions, diverge.

A listing of the FORTRAN computer program for the model is given in the Appendix.

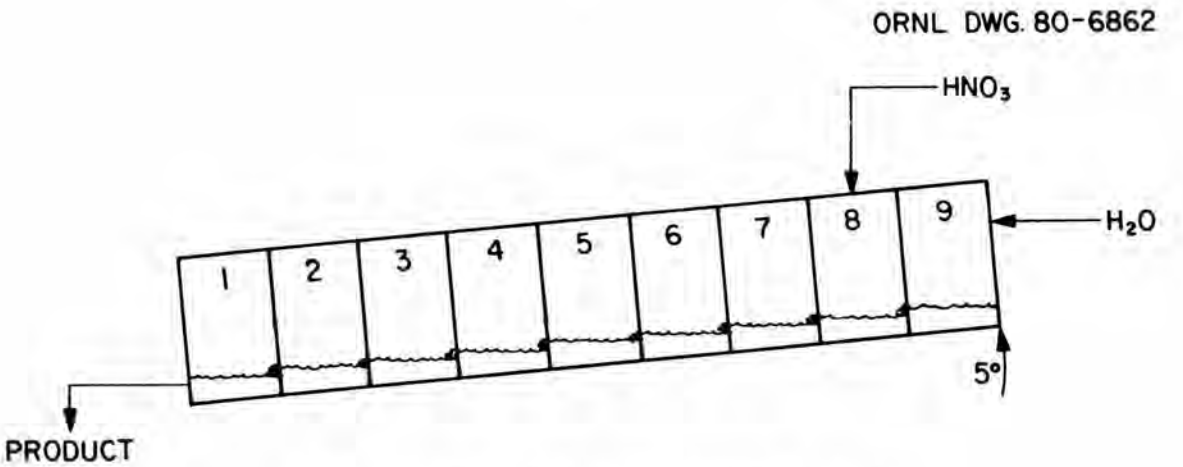

Fig. 3. Liquid flow diagram for the compartmented dissolver.

3. EXPERIMENTAL REQUIREMENTS

Basically, three different types of data were required to solve the model. The first type was the geometric volume and area of each stage. The volume of each stage was found by measuring the amount of water necessary to fill a stage to the bottom of the weir. The area was calculated from the known dimensions of the dissolver.

The data of the second type were the constants in the density-concentration correlation. The data for density vs weight fraction of HNO_3 and a linear fit of this data are presented in Fig. 4. For weight fractions less than 0.44, the constants a and b in Eq. (7) were determined by linear regression to be 1001.2 and 0.48916 g/ℓ respectively.

The final required data were the weir equation constants K and P of Eq. (4). By measuring the total mass collected for various step changes in flow, the constants K and P were calculated to be 0.9888 cm and 2.83 respectively. The value of 2.83 for the exponent P compares reasonably well to the reported values of 1.8 to 2.5 for various shaped weirs.[3]

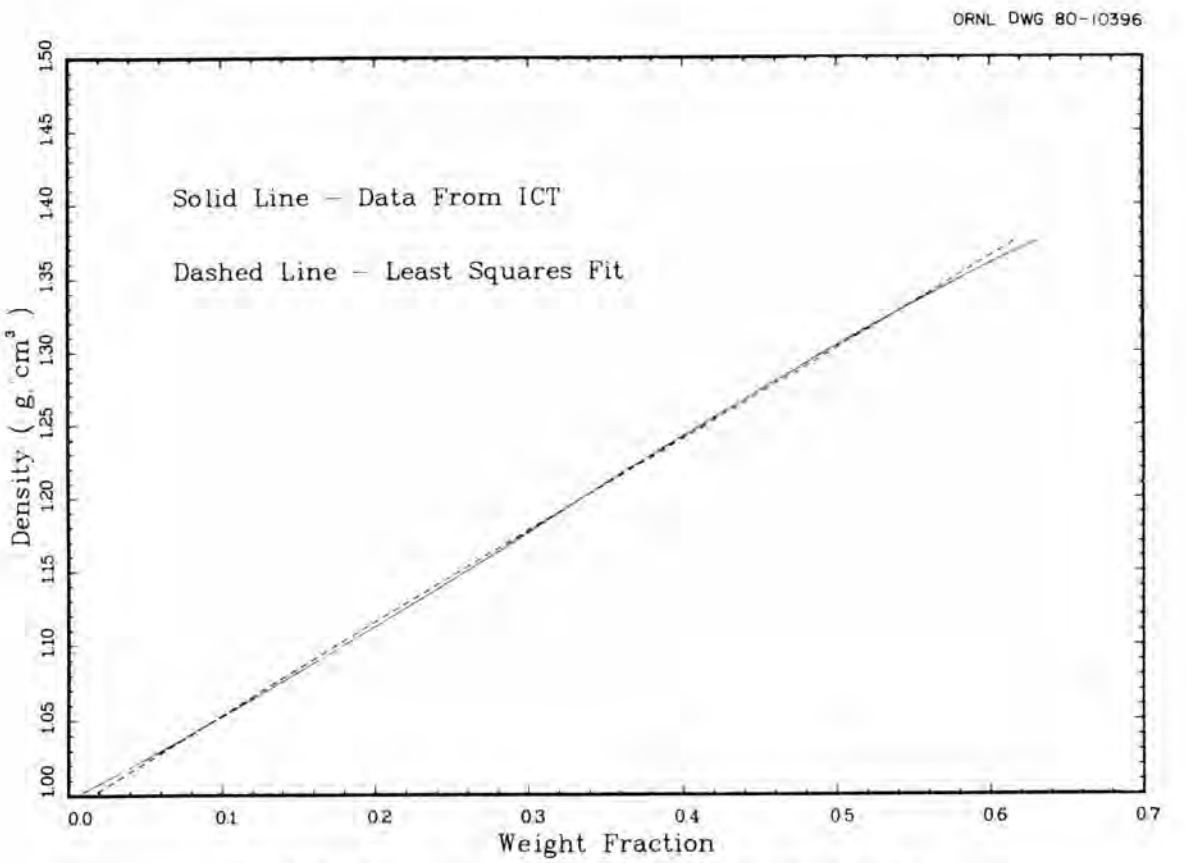

Fig. 4. Density-concentration correlation for the nitric acid-water system.

Acid concentration data were taken during an experiment in which a series of step changes in the acid and water feed rates were made. An outline of the operating conditions for this test is presented in Fig. 5. This experiment was the most severe test of the final model, covering most of the step changes in liquid flows which would be anticipated in normal operation of the dissolver (i.e., startup, small perturbations in acid flow, and shutdown).

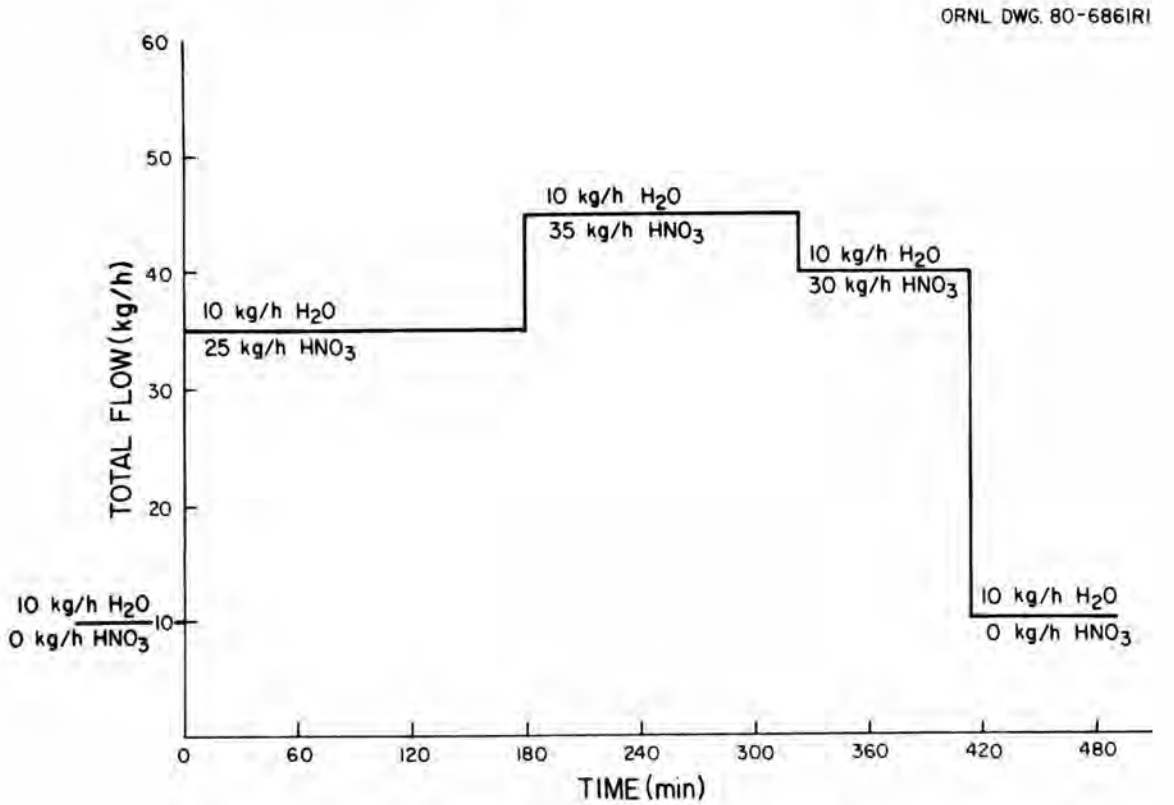

Fig. 5. Experimental test procedure for model verification.

4. RESULTS

The predictions of the model, along with the experimental results from the step change tests, are presented in Fig. 6. Also shown is a summary of actual run conditions. The predicted response and the experimentally determined response agree very well for all cases. The deviation at 160 min into the test can be explained by a known failure in the titration equipment used to collect the data. The important feature of the model is that no adjustable parameters were necessary to achieve this close agreement between experimental and predicted values. All constants in the model were chosen by separate independent tests.

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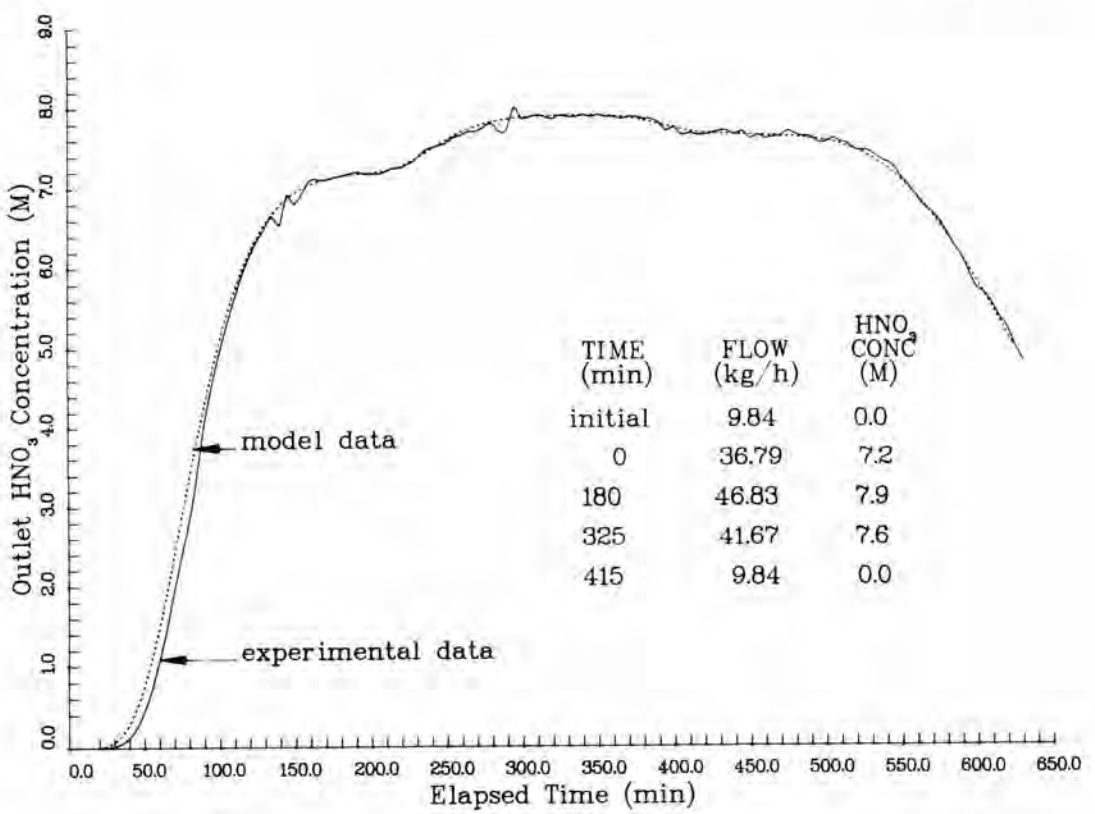

Fig. 6. Comparison of model concentration predictions with experimental data.

5. DISCUSSION OF RESULTS

Several limiting assumptions have gone into the development of the model. A linear relationship between the nitric acid concentration and solution density was used and is only applicable up to an acid concentration of 44 wt %. Caution should be exercised in applying the model outside this concentration range, since deviations from linearity are assured with the nitric acid-water system and can be seen in Fig. 4. The success of the model is highly dependent on the accuracy of the density correlation.

The experimentally determined dissolver responses to step changes of 5 to 35 kg/h were compared to the predicted responses. Agreement was good except for the largest step change of 35 kg/h. In this case, the predicted response led the measured response by 3 to 4 min. This deviation was well within acceptable limits.

Temperature fluctuations have not been addressed in this model. The model was developed assuming a constant temperature of 25°C. Including a correlation for the nitric acid-water density, temperature, and acid concentration would allow the inclusion of temperature changes, which could easily be incorporated into the model if needed.

The presence of sheared material in the dissolver significantly complicates the modeling of the process. Complications arise primarily because of backmixing during solids transfer, deviations from the assumption of ideal mixing, and depletion of acid during reaction. The effects from sheared materials were not considered; therefore, it is not advisable to use this model to describe a system with sheared material. Only a very rough prediction of performance can be expected from the model for such a system.

6. CONCLUSIONS

A model has been developed which accurately predicts the outlet response to perturbations in the feed acid flow and concentration for a 0.5-t/d rotary dissolver. This model will be useful in predicting start-up times and will provide a better understanding of how fluids flow through the dissolver. The model is limited to use in the two-component nitric acid-water system (at 25°C) with no solids present.

7. ACKNOWLEDGMENTS

The authors are grateful to M. E. Baldwin and R. J. Shannon of the dissolver operating staff for conducting the experiments and taking the requested data.

We also appreciate the helpful suggestions of J. Q. Kirkman and others associated with the dissolution effort.

8. REFERENCES

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2. O. Levenspiel, *Chemical Reaction Engineering*, 2nd ed., Wiley, New York (1972), pp. 290–91.

3. *Perry's Chemical Engineers Handbook*, 4th ed., McGraw-Hill, New York (1969), p. 18-9.

APPENDIX

FORTRAN Program Listing

```
C     THIS PROGRAM CALCULATES THE EFFECT ON THE DISSOLVER OF A STEP
C     CHANGE IN EITHER THE FLOW, CONCENTRATION, OR BOTH.
C
C
C
C     THE VARIABLES:
C     A, B, C(I), E, F(I), G, H, J, RHO(I), AND V(I)
C     ARE AS DEFINED IN THE DERIVATION OF THE ORIGINAL EQUATIONS.
C
C     I IS THE NUMBER OF THE STAGE, WHERE FEED ENTERS IN STAGE 8
C     AND EXITS IN STAGE 1.
C
C     COLD(I) IS THE PREVIOUS TIME STEP CONCENTRATION.
C     RHOOLD(I) IS THE PREVIOUS TIME STEP DENSITY.
C     VOLD(I) IS THE PREVIOUS TIME STEP VOLUME.
C     FLAG1, FLAG2, AND IFLAG ARE ERROR PROCESSING FLAGS.
C     EPS IS THE CONVERGENCE CRITERION.
C     IMAX IS THE MAXIMUM NUMBER OF TIME STEPS.
C     DELTAT IS THE TIME INCREMENT, AND RDT IS ITS RECIPROCAL.
C     P IS THE EXPONENT IN THE WEIR EQUATION, AND RP IS ITS RECIPROCAL.
C     CMAX IS THE MAXIMUM CHANGE IN CONCENTRATION BETWEEN TIME STEPS.
C     X0, X1, X2, F0, F1, AND F2 ARE SCRATCH VARIABLES USED IN CALCULATING F.
C
C     UNITS:
C             C(I)  (=) G/L
C             F(I)  (=) L/HR
C             RHO(I)  (=) G/L
C             V(I)  (=) L
C             COLD(I)  (=) G/L
C             RHOOLD(I)  (=) G/L
C             VOLD(I)  (=) L
C             DELTAT  (=) HR
C             A  (=)  G/L
C             B  (=)  NO UNITS
C             E  (=)  L
C             G  (=)  L
C             P  (=)  NO UNITS
C
C     CAUTION: DO NOT ATTEMPT TO USE THIS PROGRAM AS WRITTEN
C              FOR NITRIC ACID CONCENTRATIONS ABOVE 44%!
C
C     START:
C
      REAL J
      INTEGER FLAG1,FLAG2
      DIMENSION RHO(9),COLD(9),VOLD(9),RHOOLD(9),
     $X(300),Y(300),X11(300),Y11(300)
      COMMON E,RDT,H,C(9),G,RP,I,F(9),EPS,V(9)
C     BEGIN INITIALIZATION OF THE PROBLELM
C     SET THE CONVERGENCE CRITERION
      EPS=1.E-3
      FLAG2=0
        KPT=0
        TCOUNT=0.0
C     SET THE MAXIMUM NUMBER OF ITERATIONS
      IMAX=2000
```

```
C         ZERO ARRAYS
          DO 160 K=1,300
          X(K)=0.0
          Y(K)=0.0
          X11(K)=0.0
          Y11(K)=0.0
160       CONTINUE
C         READ IN EXPERIMENTAL DATA
          K1=125
          READ(5,310) (X11(I),Y11(I),I=1,K1)
310       FORMAT(F10.2,F10.3)
C       SET THE TIME INCREMENT
        DELTAT=1.E-2
        RDT=1./DELTAT
C       SET THE PHYSICAL PARAMETERS OF THE DISSOLVER
        A=1001.2
        B=.48916
        E=4.8
        G=0.201941
        P=2.7
        RP=1./P
        TIME=.0
C         SET UP HEADINGS FOR DATA OUTPUT
          WRITE(6,15)
15        FORMAT(1X,' TIME',5X,'C(1)',6X,'C(2)',6X,'C(3)',6X,'C(4)',6X,
       $'C(5)',6X,'C(6)',6X,'C(7)',6X,'C(8)',6X,'C(9)',6X,'F(1)')
C           SET THE STATE OF THE DISSOLVER BEFORE THE STEP CHANGE
            DO 1 I1=1,8
            I=8-I1+1
            COLD(I)=0.0
            RHOOLD(I)=A+B*COLD(I)
C           F(I) IS IN KG/HR
            F(I)=9.84
            F(I)=F(I)*1.E3/RHOOLD(I)
 1          VOLD(I)=E+G*F(I)**RP
C           SET THE VALUES OF THE STEP CHANGE
            C(9)=453.69
            RHO(9)=A+B*C(9)
C           F(9) IS IN KG/HR
            F(9)=36.79
            F(9)=F(9)*1.E3/RHO(9)
C         CALCULATE THE NEW C(I), F(I), RHO(I) AND V(I) FOR
C         EACH STAGE USING THE PREVIOUS TIME STEP VALUES.
  5       DO 10 I1=1,8
            I=8-I1+1
          H=F(I+1)*C(I+1)+COLD(I)*VOLD(I)*RDT
          J=RHO(I+1)*F(I+1)+RHOOLD(I)*VOLD(I)*RDT
          DENOM=1./(J-B*H)
          C(I)=A*H*DENOM
          RHO(I)=A*J*DENOM
C         CALCULATE NEW F(I) AND V(I) ONLY IF THE DISSOLVER IS NOT
C         FLUID HYDRAULICALLY AT STEADY STATE
          IF(ABS(F(9)-F(1)).GT.EPS) CALL SECANT
  10    CONTINUE
C       AFTER NEW VALUES ARE CALCULATED,INCREMENT TIME AND CONTINUE
        TIME=TIME+DELTAT
```

```
C         SET UP STEP CHANGE VALUES
          TMIN=TIME*60.
          IF(TMIN.GE.180.AND.TMIN.LT.325) GO TO 110
          IF(TMIN.GE.325.AND.TMIN.LT.415) GO TO 120
          IF(TMIN.GE.415) GO TO 140
          GO TO 130
140       IF(TMIN.GT.630) GO TO 150
          C(9)=0.0
          F(9)=9.84
          RHO(9)=A+B*C(9)
          GO TO 130
110       F(9)=46.83
          C(9)=497.7
          RHO(9)=A+B*C(9)
          GO TO 130
120       F(9)=41.67
          C(9)=478.8
          RHO(9)=A+B*C(9)
130       CONTINUE
C       CALCULATE MAXIMUM CHANGE IN CONCENTRATIONS BETWEEN TIME
C       STEPS.  IF CONCENTRATIONS HAVE CONVERGED, STOP CALCULATIONS.
C       IF NOT, CONTINUE UNTIL THE MAXIMUM NUMBER OF TIME STEPS
C       HAS PASSED
          TCOUNT=TCOUNT+DELTAT
        CMAX=0.0
        FLAG2=FLAG2+1
          DO 6 I1=1,8
            I=8-I1+1
  6       CMAX=AMAX1(CMAX,ABS(C(I)-COLD(I)))
        IF(CMAX.LT.EPS) GO TO 150
        IF(FLAG2.EQ.IMAX) CALL ERROR(FLAG2,IMAX)
C         RESET THE PREVIOUS TIME STEP VALUES TO PRESENT VALUES
          DO 7 I1=1,8
            I=8-I1+1
          COLD(I)=C(I)
          VOLD(I)=V(I)
  7       RHOOLD(I)=RHO(I)
C       PRINT OUT THE CALCULATED VALUES.
        WRITE(6,100) TIME,(C(I),I=1,9),F(1)
  100 FORMAT(1X,F8.4,9(2X,F8.4),2X,F8.4)
          IF(TCOUNT.LT.0.033) GO TO 5
          TCOUNT=0.0
          KPT=KPT+1
          X(KPT)=TMIN
          Y(KPT)=C(1)/63.01287
C       LOOP BACK FOR NEXT TIME STEP
        GOTO 5
 150      CALL PLOT1D(X,Y,KPT,X11,Y11,K1)
          STOP
        END
```

```
C               THIS SUBROUTINE PROCESSES ANY ERRORS WHICH MAY
C               OCCUR DURING THE CALCULATIONS AND PRINTS AN
C               APPROPRIATE ERROR MESSAGE.
                SUBROUTINE ERROR(IFLAG,IMAX)
                IF(IFLAG.EQ.1500) GO TO 10
                IF(IFLAG.EQ.-10) GO TO 20
                IF(IFLAG.EQ.-11) GO TO 30
                IF(IFLAG.EQ.IMAX) GO TO 40
          GO TO 60
10        WRITE(6,15)
15        FORMAT(' SECANT METHOD IS NOT CONVERGING')
          GO TO 50
20        WRITE(6,25)
25        FORMAT(' SECANT METHOD CANNOT FIND STARTING VALUES')
          GO TO 50
30        WRITE(6,35)
35        FORMAT(' F HAS NO ROOT')
          GO TO 50
40        WRITE(6,45)
45        FORMAT(' NO CONVERGENCE OVER TIME')
60        WRITE(6,55)
55        FORMAT(' ERROR IN ERROR PROCESSING')
50        CONTINUE
                STOP
                END
C               THIS SUBROUTINE CALCULATES THE NEW F(I) AND V(I)
C               USING THE PREVIOUS TIME STEP VALUES
                SUBROUTINE SECANT
                COMMON E,RDT,H,C(9),G,RP,I,F(9),EPS,V(9)
                INTEGER FLAG1
                FLAG1=0
C               SET GUESS VALUES TO LEFT AND RIGHT OF ZERO
C               (X0 HAS NEGATIVE VALUE AND X1 HAS POSITIVE VALUE)
                X0=F(I)
                X1=0.0
                CON=E*RDT-H/C(I)
                TEMP=G*RDT
C                 MAKE SURE X0 IS NEGATIVE
                  DO 1 K1=1,500
                  K=500-K1+1
                  X0=X0-0.1
                  IF(X0.LT.0.0) GOTO 1
                  F0=CON+X0+TEMP*X0**RP
                  IF(F0.LT.0.0) GOTO 5
   1              CONTINUE
C               IF X0 IS POSITIVE, PRINT APPROPRIATE ERROR MESSAGE
                FLAG1=-10
                CALL ERROR(FLAG1,IMAX)
C                 MAKE SURE X1 IS POSITIVE
 5                DO 10 K=1,500
                  X1=X1+0.1
                  F1=CON+X1+TEMP*X1**RP
                  IF(F1.GT.0.0) GOTO 15
  10            CONTINUE
C               IF X1 IS NEGATIVE, PRINT APPROPRIATE ERROR MESSAGE
                FLAG1=-11
```

```
              CALL ERROR(FLAG1,IMAX)
C               IF SECANT METHOD HAS CONVERGED, PREPARE TO RETURN
   15           IF(ABS(F0).LT.EPS.OR.ABS(F1).LT.EPS) GOTO 25
                FLAG1=FLAG1+1
C               IF SECANT METHOD IS NOT CONVERGING, PRINT
C             APPROPRIATE ERROR MESSAGE
                IF(FLAG1.EQ.IMAX) CALL ERROR(FLAG1,IMAX)
C                 CALCULATE NEW END POINT USING THE SECANT METHOD
                  ALPHA=(X1-X0)/(F1-F0)
                  X2=X1-ALPHA*F1
                  F2=CON+X2+TEMP*X2**RP
C                   REPLACE ONE END POINT WITH NEW END POINT
C                   WHERE THE OLD AND NEW VALUE HAVE THE SAME SIGN
                    IF(ABS(F2).LT.EPS) GOTO 25
                    IF(ABS(F1/ABS(F1)-F2/ABS(F2)).GT.EPS) GOTO 20
                    X1=X2
                    F1=F2
                    GOTO 15
   20               X0=X2
                    F0=F2
                    GOTO 15
C             PREPARE TO RETURN VALUE OF F(I) AND V(I)
   25         IF(ABS(F0).LT.EPS) F(I)=X0
              IF(ABS(F1).LT.EPS) F(I)=X1
              IF(ABS(F2).LT.EPS.AND.FLAG1.GT.0) F(I)=X2
              V(I)=E+G*F(I)**RP
              RETURN
              END
C
C
C
        SUBROUTINE PLOT1D(X,Y,K,X11,Y11,K1)
        DIMENSION X(300),Y(300),X11(300),Y11(300),IPAK(150)
        CALL CALCMP
        CALL COMPLX
        CALL MX1ALF('STANDARD',')')
        CALL MX2ALF('L/CSTD','(')
        CALL MX3ALF('INSTRU','+')
        CALL TITLE(' $',
     1-100,'E(LAPSED )T(IME (MIN))$',100,
     2'O(UTLET )HNO+LH.5)3+LXHX) C(ONCENTRATION ()M)$',100,8.25,6.0)
        CALL BLNK3(-0.015,-.12,-.1,6.5,0)
        CALL BLNK4(-.1,8.95,-.015,-.12,0)
        CALL GRAF(0.,50.,650.,0.,1.,9.)
        CALL BLNK1(.125,.25,0.0,6.5,0)
        CALL BLNK2(0.0,8.95,.125,.25,0)
        CALL YGRAXS(0.0,.2,9.,6.0,' $',-100,0.,0.)
        CALL XGRAXS(0.0,10.,650.,8.25,' $',-100,0.0,0.0)
        CALL RESET('BLNKS')
        CALL MARKER(2)
        CALL DOT
        CALL SPLINE
        CALL CURVE(X,Y,K,0)
        CALL RESET('DOT')
        CALL CURVE(X11,Y11,K1,0)
        CALL RLVEC (110.,1.08,60.0,1.08,301)
```

```
CALL RLMESS('(MODEL DATA)$',100,115.,3.74)
CALL RLVEC (110.,3.74,83.,3.74,301)
CALL RLMESS('(EXPERIMENTAL DATA)$',100,115.,1.08)
CALL RLMESS('HNO+LH.5)3+EXLX)$',100,520,5.25)
CALL RLMESS('   TIME      FLOW     CONC$',100,310.0,4.90)
CALL RLMESS('   ((MIN))     ((KG/H))     (()M)$',100,310.0,4.55)
CALL RLMESS('  (INITIAL)      9.84      0.0 $',100,310.0,4.0)
CALL RLMESS('     0       36.79      7.2 $',100,310.0,3.5)
CALL RLMESS('   180       46.83      7.9 $',100,310.0,3.0)
CALL RLMESS('   325       41.67      7.6 $',100,310.0,2.5)
CALL RLMESS('   415        9.84      0.0 $',100,310.0,2.0)
CALL ENDPL(1)
CALL DONEPL
STOP
END

 0
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