Capillary Fill Time & Meniscus Shape: *An asymmetric, nonequal contact angle, coplanar cavity study*

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Abstract:

The fill time of a fluid through a non-symmetric, coplanar cavity was determined using a modified Washburn equation as a function of surface energy, viscosity, and cavity parameters. An iterative routine was used to determine the radius of curvature as a fluid traverses an asymmetric, coplanar cavity. From the numerical solutions for the radius of curvature along the length of the cavity, a time averaged radius of curvature used in the prediction of fill time. Based on these simulations and reasonable estimations of fluid properties, the fastest expected fill time due to capillary action alone is ~8 seconds.

Introduction:

The rate at which a fluid traverses a cavity or pore is of great importance to many industries. Rossen highlights a particular example of which in his study of foams passing through symmetric and asymmetric pore. In his study, he uses a similar but more rigorous analysis to predict the minimum pressure drop required to maintain a flowing foam in the industrial oil extraction technique called "gas enhanced-oil-recovery" (EOR). My interest in this problem focuses on the specifics of filling an imprint lithography mold by capillary action. Understanding how the mold design and fluid properties affect the fill characteristics is crucial to developing a commercially viable process. Two fill characteristics are looked at in this study: fill time and meniscus shape.

Background:

Dr. Paul's paper on polymer impregnation of concrete uses the well known Washburn Equation, shown below, to model the fill time of a vertical cylindrical capillary by a polymer solution [3]. The Washburn equation describes the position of an interface dependence on a balance of surface energy and pressure, collectively, to viscous dissipation. Starting from the force balance, I have derived a modified Washburn Equation for a Newtonian fluid in a rectilinear cavity.

Washburn Equation (cylindrical):

$$\frac{dx}{dt} = \frac{2\pi R\gamma\cos\theta + \pi R^2 P}{8\pi\mu x} \qquad [1]$$

Washburn Equation (rectilinear):

$$\frac{dx}{dt} = \frac{\left(H^2\gamma / R\right)}{\left(24\mu x\right)} \qquad [2]$$

Several assumptions were made in the above derivation. The fluid is assumed to be Newtonian. In practicality, this is a good approximation; the fluid consists mainly of solvent and monomer. The small deviations from the mean distance, H, between surfaces is assumed to negligibly affect fill time. Further simulation should be performed to validate this assumption. No slip boundary conditions were applied to the upper and lower surfaces.

By comparison of the two equations, one can see several obvious differences. The pressure term in the cylindrical Washburn represents the pressure head at the inlet of a cylinder. This pressure head can be due to a fluid supply or pressurized pipe. In our case, the pressure head is due to the fluid used to fill the cavity. It has a height, D, above the position of the cavity. This pressure head does not contribute significantly to the numerator of the modified Washburn equation and has been ignored. The difference in the surface tension terms and the denominator constant are relics of the different geometries.

Experimental System:

A fluid is to fill a cavity between two coplanar plates via capillary action. A drop along one edge of the plate is the fluid source. The distance between the two surfaces is defined by the height, H. The top plate has a lithographic pattern etched in the surface such that the profile of the pattern has a depth (2α), and period (λ). The fluid comprised of organic monomer, organosilicon monomer, and organosilicon polymer has mass fraction of 1:1:1 respectively.

Model System:

A fluid is to fill a cavity between two coplanar plates via capillary action. A fluid of height, D, is the fluid source and provides a pressure head. The fluid source height, D, is great enough to fill the cavity. The average distance between the two surfaces is defined by the height, H. The top plate has periodic sinusoidal pattern with amplitude (α), and wavelength (λ). The fluid is incompressible and Newtonian having constant density (ρ) and viscosity (μ). The fluid and the top surface form a contact angle, θ_1. The fluid and the bottom plate form a contact angle θ_2.

Table 1. Comparison of Experimental System and Model System.

Experimental System	Model
1:1:1 solvent: monomer: polymer	Newtonian Fluid of constant viscosity and density
Top plate has anisotropic etched pattern of depth, 2α, and period, λ.	Sinusoidal pattern of amplitude, α, and wavelength, λ.
Plates are 1 square inch.	Plates of length (L), 2.5 cm. Neglect Edge effects.
Slightly non-coplanar plates	Coplanar plates
$0° < \theta_1 < 30°$ $50° < \theta_2 < 90°$	$\theta_1 = 30°$ $\theta_2 = 60°$
Fluid feed by a convex drop of radius R' on one edge.	Fluid feed with fluid height, D. Initially D = L*H/ 1 microns

Model Schematic:

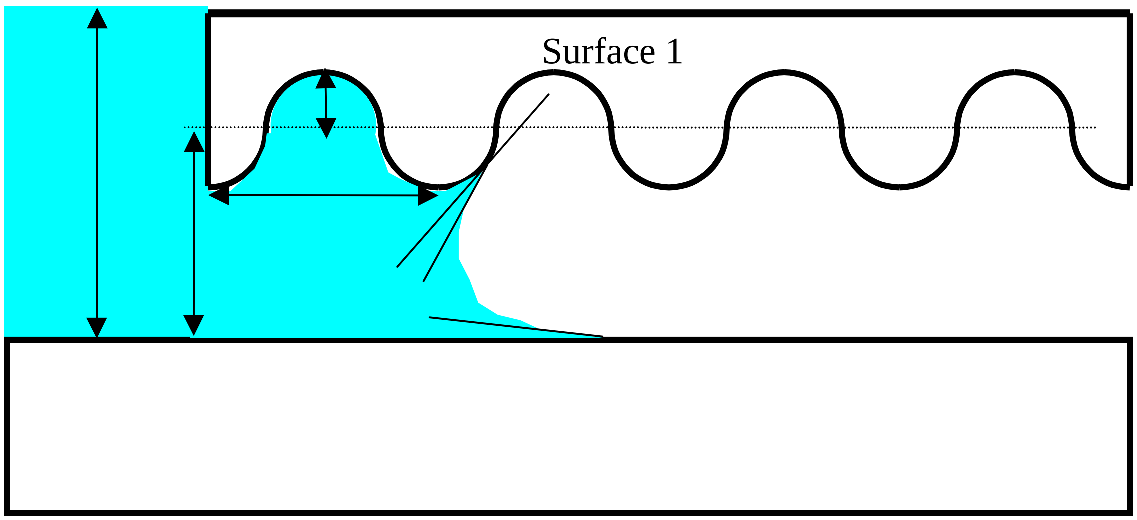

Figure 1. Model System having mean distance, H, between two coplanar plates. The upper surface is sinusoidal having amplitude, α, and wavelength, λ. Each surface forms a distinct contact angle with the meniscus. The cavity is fed fluid by a pressure head of height, D.

Simulation Methodology:

Rossen has demonstrated the shape of lamellae as it passes through a cavity of various shapes. This same method can be applied to this problem [1,2]. By solving for position along the cavity as a function of time, the shape of the meniscus has been determined as a function of time. As Rossen notes, the average pressure difference is affected be shape of the capillary [1,2]. Using a time averaged interfacial pressure drop, the pressure drop along the length of the cavity was calculated at a point along the length of the cavity. The radius of curvature is calculated from our solutions to meniscus shape. The velocity at various points along the cavity predict the time associated at these points. The integral over the time in one wavelength of the system gives the time averaged radius of curvature. This radius can then be used to solve for the cavity fill time.

As was shown in class, the meniscus shape for many instances can be solved by pure geometric considerations. In the posed problem with its constraints, the curvature of the meniscus can be solved geometrically. In the sinusoidal surface intersection of a cylindrical meniscus, the easiest method of determining the correct curvature was by defining each surface by a vector and parameterizing each surface. The parameterized defined surfaces are shown below.

Upper Surface [3]

$$s(t) = t\vec{i} + (H + \alpha \sin(\frac{2\pi x}{\lambda}))\vec{j}$$

Lower Surface [4]

$$g(\gamma) = \gamma\vec{i}$$

Meniscus [5]

$$\eta(\beta,\gamma) = (x_c(\gamma) + R\cos(\beta))\vec{i} + (y_c(\gamma) + R\sin(\beta))\vec{j}$$

Using the above equations, a shooting method was used to find where the meniscus would intersect the upper surface. A position along the wavelength was set; starting at zero and stepping through one wavelength. A radius of curvature was guessed and swept through angles from β_1 to zero radians as depicted in Figure 2 below.

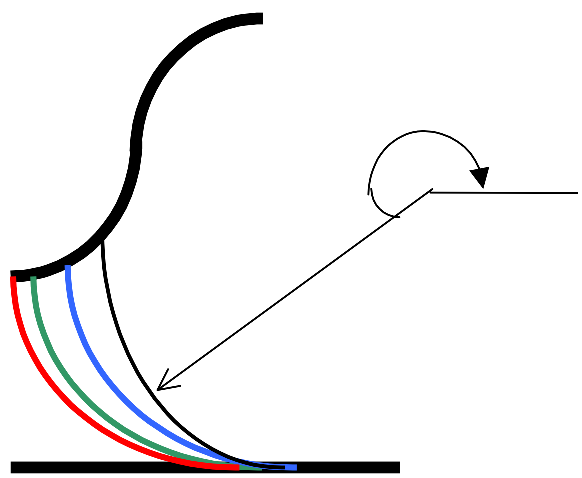

Figure 2. Depiction of Shooting Method as R is increased and β_2 is swept from β_1 to 0^r.

Once the meniscus-upper surface interface was found, a dot product of the tangents was used to calculate the contact angle. If the contact angle met the constraint of 60º, the curvature at that position was found and the next step was performed. The Fortran code used to solve these equations is shown in Appendix I. It contains a straightforward methodology and is descriptively commented.

Upper Surface – Meniscus Dot Product [6]

$$\cos\theta_2 = \frac{(2\pi\alpha/\lambda)\cos\beta_2 \cos(\frac{2\pi t}{\lambda}) - \sin\beta_2}{\left[1 + ((2\pi\alpha/\lambda)\cos(2\pi t/\lambda))^2\right]^{1/2}}$$

Simulation Parameters:

This iteration method was used to calculate the radius of curvature at 20 points along one wavelength. Several system parameters have been varied. H ranged from 0.1 microns to 1 micron. α represents the depth of a pattern in the imprint mold. It ranges from 0.05 microns to 0.2 microns. λ represents the twice feature width. It ranges from 0.05 microns to 0.2 microns. Contact angles remained constant.

Results:

The radius of curvature has been calculated for a variety of systems. Several representative systems are graphically depicted below. Initial simulations were carried using an allowable angular error of 0.005 radians and length error of 0.001microns. Using these values, the first radiuses to meet the constraints are shown below.

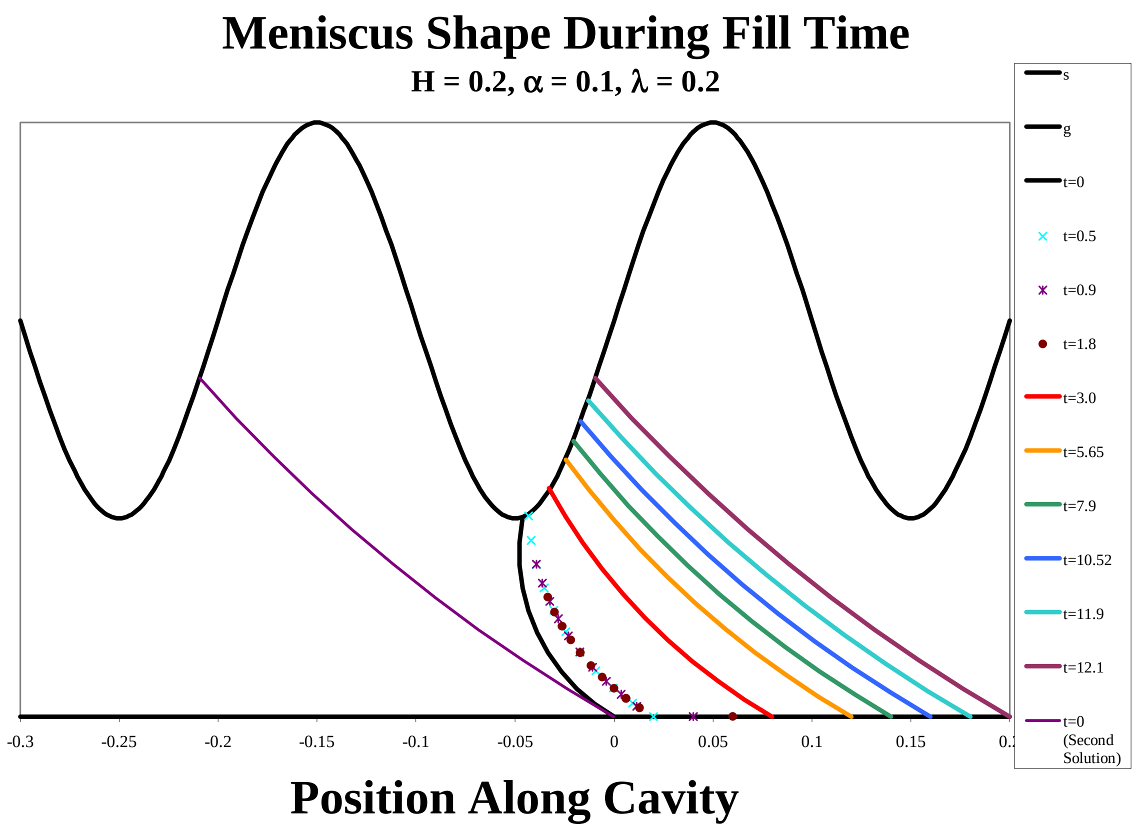

Figure 3. First Radius of Curvature of Meniscus Found using the Shooting Iteration Scheme

Two important observations can be made: 1) the radius of curvature slowly increases along the length of the cavity, 2) the radius of curvature at the beginning of the wavelength and the end of the wave length are different. The second observation is noted by the solutions at t = 0, t=12.1, and t=0 (second solution). This indicates multiple solutions to the radius of curvature are possible.

Due to this result, a second set of simulations was performed and the results shown below. For convenience of illustration not all solutions are plotted. Notice the four solutions to this particular system. From observation from numerous plots, the number of solutions increase with increasing H and with decreasing λ. This can be explained by the fact that as H increases or l decreasing, there are more periods of oscillation over the allowed range of radii ($0 \rightarrow \infty$).

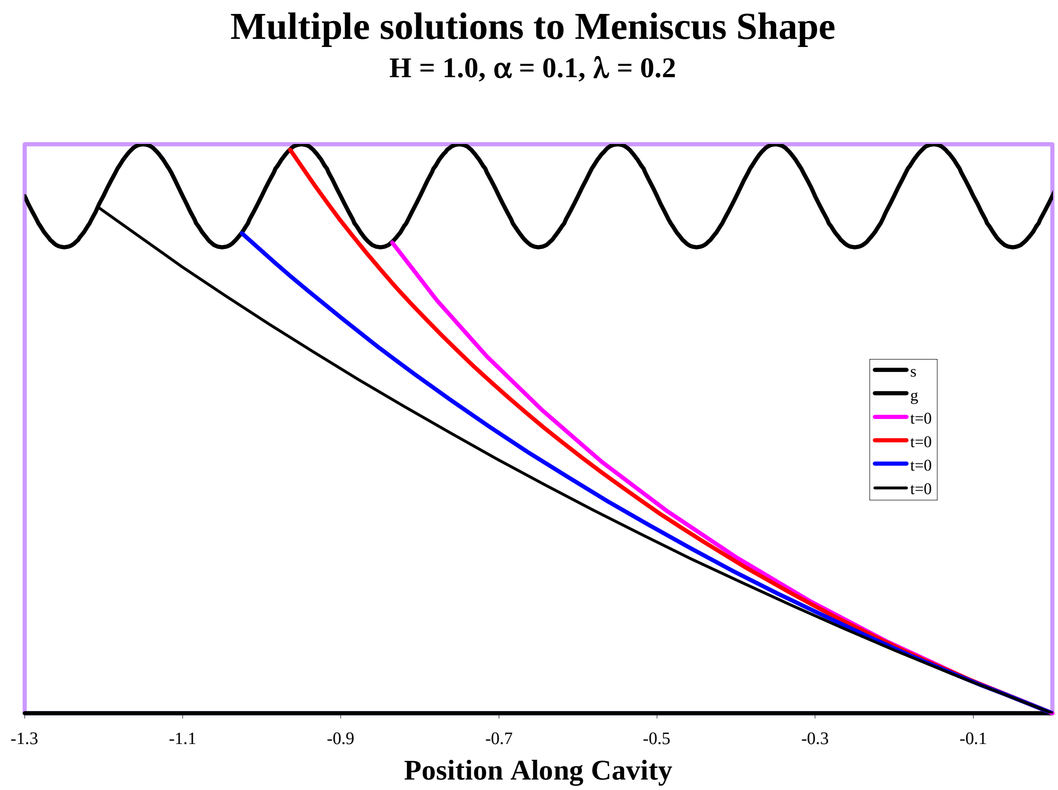

Figure 4. Plot of Multiple Allowable Radiuses Found for A Single Point.

In order keep the scope of the project manageable, the minimum radius of curvature solution was used to carry out the prediction of fill time. An example of this is shown in figure 5 below. Upon careful inspection of the figure, the time labeled solutions indicate that at certain locations the meniscus will advance along the surface then retract as the position of lower surface-meniscus contact point advances.

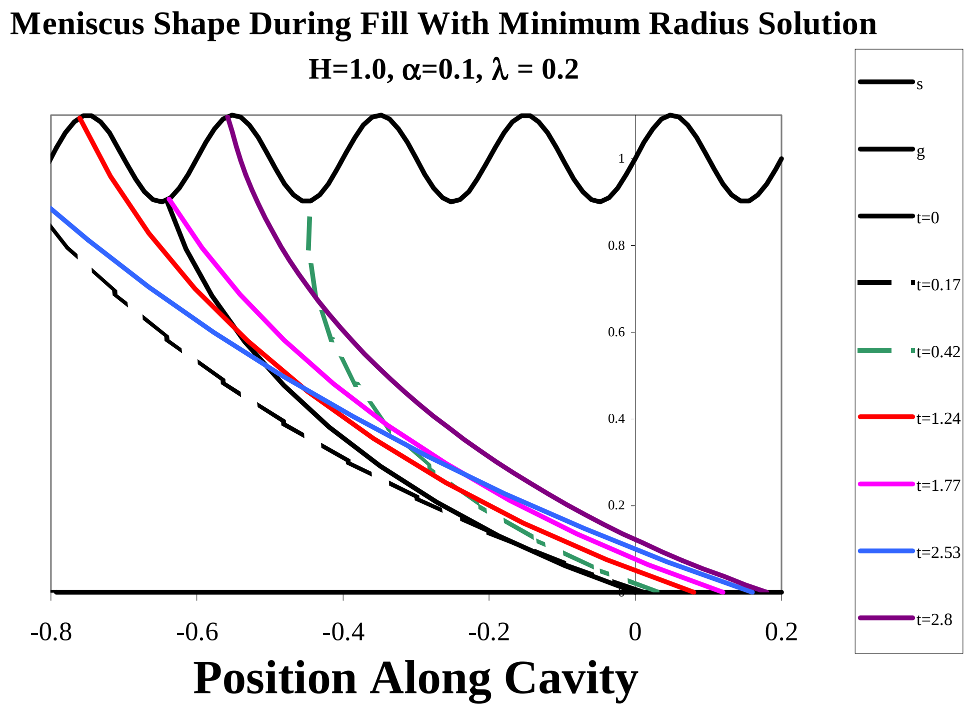

Figure 5. Plot of Minimum Radius Solution for H= 1 micron, α = 0.1 microns and λ = 0.2 microns.

From these minimum radius of curvature solutions the fill time can be projected using the modified Washburn equation. It should be noted due to the complexity of the system several important considerations where neglected. The volume in the cavity as a function of time was not considered. The method of filling the cavity also was ignored. No information regarding bubble formation could be extracted from this simulation as was hoped.

Based on the above solutions for the radius of curvature, the Washburn equation was used to predict the fill time for fluids of various surface tensions and viscosities. An example of the meniscus position in time is plotted in figure 6. Using reasonable estimates of possible fluid properties, the fill times are tabulated below.

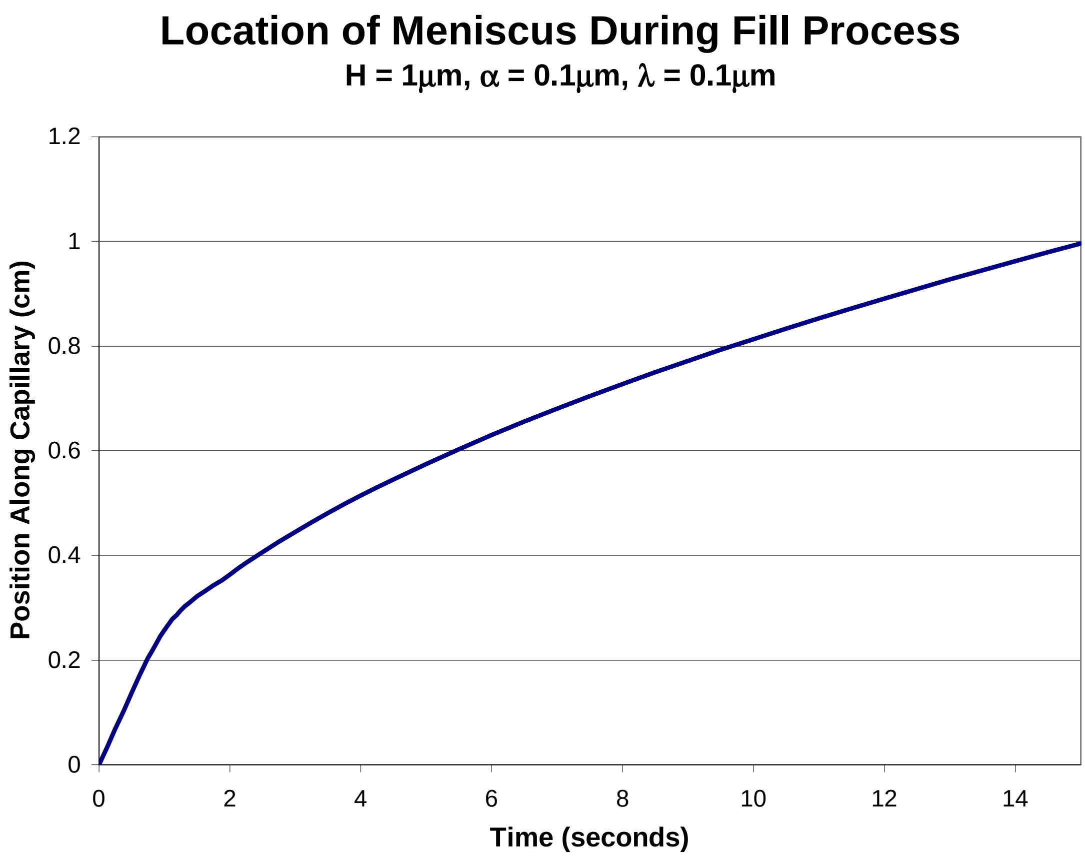

Figure 6. Meniscus Position as a Function of Time Based on the Radius of Curvature Simulations and the Washburn Equation.

Table 2. Fill Times (seconds) for Various Viscosities, Surface Tensions, and System Parameters.

Viscosity	γ = 30 dynes/cm	γ = 50 dynes/cm	γ = 70 dynes/cm
0.01	8	4.8	3.4
0.1	80	48	34.3
1	800	480	342.9

Viscosity (P)	H=1, α=0.1, λ = 0.2	H=1, α=0.1, λ = 0.1	H=0.2, α=0.1, λ = 0.2	H=0.2, α=0.1, λ = 0.1
0.001	28.56	15.12	112	56
0.01	285.6	151.2	1120	560
0.1	2856	1512	11200	5600
1	28560	15120	112000	56000

Based on these fill time, a minimum fill time of ~ 8 seconds can be predicted for the current experimental formulations. In practice, 8 seconds is similar to that which is observed. However, this is not commercially viable method of filling the imprint lithography mold as a sole source of flow. Fortunately, the upper surface of our experimental system can be actuated causing pressure drive flows filling the cavity in a production worthy time.

Conclusions:

The radius of curvature along the length of a sinusoidal surface has been calculated. A method of predicting the meniscus location in time based on a time average pressure drop across an interface has been produced. The iterative solution to the Washburn equation and meniscus shape has provided valuable insight into the process conditions of a fluid filling a capillary. Capillary action must be assisted by another driving force in order to produce acceptable fill times.

Future Work:

Several further considerations may be of interest in the future. The rate of filling is dependent on the radius of curvature along the length of the cavity. The multiple solution to the radius of curvature poses questions beyond the scope of this report but are of great interest. A convex fluid source is more indicative of the actual system and would add complexity to the system. Another assumption of identical features on the upper surface could be relaxed to include different periods representing different feature sizes on the same mold. The most important considerations of future interest is determination of the actual filling profiles. This would determine whether or not bubbles are created during the fill process.

References:

1. Rossen, William R., "Theory of Mobilization Pressure Gradient of Flowing Foams in Porous Media, III. Asymetric Lamella Shapes", J. Colloid and Interface Sci. V. 136. No.1, pp.36-53, 1990.
2. Rossen, William R., "Theory of Mobilization Pressure Gradient of Flowing Foams in Porous Media, I Incompressible Foam", J. Colloid and Interface Sci.. V. 136. No.1, pp. 1-16, 1990.
3. Paul, D.R., Fowler, D.W., " Surface Impregnation of Concrete Bridge Decks with Polymers", J. Applied Polymer Sci. V. 19, pp. 281-301 Apr 1975.

Appendix I. Shooting Method Code for Solving for Radius of Curvature along the Length of a Cavity.

```
C*************************************************************
C                   MAIN PROGRAM
C
C                   Matthew Colburn
C
C                   Curvature of Meniscus as Fluid Traverse
C                   A Non Symetric Pore With Nonequal Contact Angles
C*************************************************************

          Program Curvature
          Implicit None


C         Initialize Variable

          Real H, A, W, O1, O2, B1, LOOP


          Real B2, PI, R, T, XC, YC, G, Z, CONSTR,ITER
          Parameter (PI=3.14159)
          Real MaxG, StepG, LOOPKILL, StepR, StepB
          Real SurfErr, AngErr




C         Define Fixed Values & Comparison Functions


C         curv_1.txt constants
C         H = 0.2
C         A = 0.1
C         W = 0.2
C         curv_2.txt constants
C         H = 0.2
C         A = 0.1
C         W = 0.1
C         curv_3.txt constants
C         H = 0.2
C         A = 0.05
C         W = 0.1
C         curv_4.txt values
C         H = 0.2
C         A = 0.05
C         W = 0.2
C         curv1_1.txt values
C         H = 0.1
C         A = 0.05
C         W = 0.2
C         curv1_2.txt values
C         H = 0.1
```

```
C       A = 0.05
C       W = 0.1
C       curv1_3.txt values
C       H = 0.2
C       A = 0.1
C       W = 0.05
C       curv4_1.txt
C       H = 0.4
C       A = 0.1
C       W = 0.2
C       curv8_2.txt
C       H = 0.8
C       A = 0.1
C       W = 0.2
C       curv3_1.txt
C       H = 0.2
C       A = 0.1
C       W = 0.2
C       curv3_1b.txt
C       H = 0.2
C       A = 0.1
C       W = 0.2
CC      curv3_1bb.txt - smaller error allowed
C       H = 0.2
C       A = 0.1
C       W = 0.2
CC      curv3_1bc.txt - smaller error allowed & 2*W range
C       H = 0.2
C       A = 0.1
C       W = 0.2
C       curv3_2.txt
C       H = 1.0
C       A = 0.1
C       W = 0.2
C       curv3_3.txt
C       H = 1.0
C       A = 0.1
C       W = 0.1
C       curv3_3b.txt - smaller error allowed (t<0.001 s-n<0.0005 & 2 W range
C       H = 1.0
C       A = 0.1
C       W = 0.1
C       curv3_3c.txt - smaller error allowed (t<0.001 s-n<0.0005 & 0.5 W range
C       H = 1.0
C       A = 0.1
C       W = 0.1
C       curv4_1.txt - solve for multiple solutions
        H = 1.0
        A = 0.1
        W = 0.2


C       Format Statements for Outputs
```

```
C       open(100, file='curv3_1bc.txt',status='new')
C       open(200, file='curvrang.txt',status='new')
C       open(100, file='curv3_3b.txt',status='new')
        open(100, file='curv4_1.txt',status='new')




        O1 = (30*PI/180)
        O2 = (60*PI/180)

C       Iteration Constraints
        MaxG = (0.1*W)
        StepG = (0.05*W)
C       MaxG = (2*W)
C       StepG = (0.1*W)


C       SurfErr = 0.001
C       AngErr = 0.001
        SurfErr = 0.001
        AngErr = 0.001
        StepB = (0.0005*PI/180)
        StepR = 1.0005


        Write (*,*) "Program Running....."
        Write (*,*) "                 DO NOT STOP PROGRAM"

        WRITE (*,*) "Thanks, Matt"




C       Set Initial Values of Variables

        G = 0
        B1 =  asin(cos(O1)) + PI
        B2=B1-0.0001


C       Define Functions (T, Z,CONSTR,
        R  = ((H-A)/(1+3**0.5/2) )
        YC = -R*sin(B1)
        XC = G - R*cos(B1)
        T = XC+R*cos(B2)
        CONSTR =H+A*sin(2*PI/W*(G+R*( cos(B2)-cos(B1) ) ))
        &                              -R*(sin(B2)-sin(B1))
         Z=(-2*PI*A/W*cos(B2)*cos(2*PI*T/W) + sin(B2))/(1+(
        &                   2*PI*A/W*cos(2*PI*T/W))**2)**(0.5)



        WRITE (100,70) "H =", H,"A =", A,"W =", W,"B1 =", B1
```

```
10      FORMAT (f10.4)
20      format (12f10.4)
30      format (12a7)
40      format (a7)
50      format (a7,f10.4)
60      format (7(a7,f10.4))
70      format (8(a5,f8.4))
80      format (4(a5,f8.4))

C       First Do Iterates on G, the stepping on the lower surface
C       Second Do Iterates on R searching for correct curvature
C       Third Do Iterates on T to get correct T,B2 combination

        LOOPKILL=0
        LOOP = 0
C       Steps G from 1 to W (one full wavelength)
C       DO G = 0,MaxG,StepG
        DO G = 0,MaxG,StepG
                ITER = (100*G/MaxG)
                write (*,*) "Program ",ITER, "% Complete"
                R= (3**(0.5)/2*(H-A))
                B2 = B1 - 0.001
C       This steps R until the Meniscus touches the Upper surface
C       somewhere between B1 & 0 (which is stepped in the next loop)
                DO WHILE (LOOP .eq. 0)
                        CONSTR =H+A*sin(2*PI/W*(G+R*( cos(B2)-cos(B1) ) ))
        &                                       -R*(sin(B2)-sin(B1))
C       This Steps B2 from B1 to Zero if the Meniscus surface isn't
C       touching the top surface between B1 & B2. Once in contact it
C       calculates the contact angle & compares to desired O2
                        DO WHILE ( ( (CONSTR .gt. 0 ).and.(B2 .gt. 0)).and.
        &                       (LOOPKILL .eq.0) )
                                IF (CONSTR .le. SurfErr ) then
                                        YC = -R*sin(B1)
                                        XC = G - R*cos(B1)
                                        T = XC+R*cos(B2)
                                        Z=(-2*PI*A/W*cos(B2)*cos(2*PI*T/W) + sin(B2))/(1+(
        &                                 2*PI*A/W*cos(2*PI*T/W))**2)**(0.5)
                                        IF      ( (CONSTR .le. SurfErr )
        &                                       .and.( ABS( Z-cos(O2) ).le. AngErr ))  then
                                                WRITE (100,70) "Z=",Z,"CONS",CONSTR,
        &                                       "R=",R,"B2=",B2,
        &                                       "G=",G,"T=",T,"XC=",XC,"YC=",YC
                                                LOOPKILL = 1
C                                               LOOP = 1
                                        ELSE IF (( CONSTR .le. SurfErr ).and.
        &                                       ( ABS( Z-cos(O2) ).gt. AngErr) ) then
                                                LOOPKILL = 1
                                        END IF
                                ELSE
                                        B2 = B2-STEPB
                                        T = XC+R*cos(B2)
                                        CONSTR =H+A*sin(2*PI/W*(G+R*( cos(B2)-cos(B1) ) ))
        &                                       -R*(sin(B2)-sin(B1))
                                END IF
```

```
                    END DO
C         These reset B2 to B1 for another R step
                    R = R*StepR
                    B2 = B1-0.001
                    LOOPKILL = 0
C                   if (R>20) then
                    if (R>10) then
                              LOOP = 1
                    endif
               END DO
C         These reset B2 & R for another G step
               LOOPKILL = 0
               LOOP = 0
          END DO
          CLOSE (100)

          END PROGRAM
```

Appendix II. Sample of Code Output from Curv1_2.txt

Surface Parameters (microns)

H = 0.2
α = 0.1
λ = 0.1

Variable Definitions

Variable	Description
Z	Dot Product of S and η
CONS	Difference Between S and η for above Z
R	Radius of Curvature When Constraints Met
B2	Angle from vector i
G	Position R was “Shot” From
T	S Parameter that Determines Location of Intersection
Yc, Xc	Position of Center of Cylinder

```
Z=  .4990 CONS  .0010  R=  .0562  B2= 3.1191  G=  .0000  T= -.0281  XC=  .0281  YC=  .0487
Z=  .4991 CONS  .0010  R=  .0604  B2= 3.1850  G=  .0025  T= -.0276  XC=  .0327  YC=  .0523
Z=  .4992 CONS  .0010  R=  .0652  B2= 3.2491  G=  .0050  T= -.0272  XC=  .0376  YC=  .0565
Z=  .5014 CONS  .0010  R=  .0708  B2= 3.3115  G=  .0075  T= -.0269  XC=  .0429  YC=  .0613
Z=  .4978 CONS  .0010  R=  .0771  B2= 3.3710  G=  .0100  T= -.0265  XC=  .0485  YC=  .0668
Z=  .4990 CONS  .0010  R=  .0843  B2= 3.4288  G=  .0125  T= -.0262  XC=  .0547  YC=  .0730
Z=  .5009 CONS  .0010  R=  .0927  B2= 3.4845  G=  .0150  T= -.0259  XC=  .0613  YC=  .0802
Z=  .4992 CONS  .0010  R=  .1021  B2= 3.5375  G=  .0175  T= -.0256  XC=  .0685  YC=  .0884
Z=  .4989 CONS  .0010  R=  .1129  B2= 3.5883  G=  .0200  T= -.0254  XC=  .0765  YC=  .0978
Z=  .4990 CONS  .0010  R=  .1254  B2= 3.6369  G=  .0225  T= -.0251  XC=  .0852  YC=  .1086
Z=  .4988 CONS  .0010  R=  .1399  B2= 3.6834  G=  .0250  T= -.0249  XC=  .0949  YC=  .1211
Z=  .5010 CONS  .0010  R=  .1567  B2= 3.7280  G=  .0275  T= -.0247  XC=  .1059  YC=  .1357
Z=  .5004 CONS  .0010  R=  .1764  B2= 3.7702  G=  .0300  T= -.0245  XC=  .1182  YC=  .1527
Z=  .4989 CONS  .0010  R=  .1994  B2= 3.8104  G=  .0325  T= -.0243  XC=  .1322  YC=  .1727
Z=  .5000 CONS  .0010  R=  .2271  B2= 3.8490  G=  .0350  T= -.0241  XC=  .1486  YC=  .1967
Z=  .4980 CONS  .0010  R=  .2602  B2= 3.8855  G=  .0375  T= -.0239  XC=  .1676  YC=  .2253
Z=  .4977 CONS  .0010  R=  .3008  B2= 3.9205  G=  .0400  T= -.0237  XC=  .1904  YC=  .2605
Z=  .4986 CONS  .0010  R=  .3515  B2= 3.9540  G=  .0425  T= -.0235  XC=  .2183  YC=  .3044
Z=  .4981 CONS  .0010  R=  .4158  B2= 3.9859  G=  .0450  T= -.0233  XC=  .2529  YC=  .3601
Z=  .4978 CONS  .0010  R=  .4997  B2= 4.0162  G=  .0475  T= -.0231  XC=  .2974  YC=  .4328
Z=  .4985 CONS  .0010  R=  .6146  B2= 4.0453  G=  .0500  T= -.0230  XC=  .3573  YC=  .5323
Z=  .4976 CONS  .0010  R=  .7781  B2= 4.0729  G=  .0525  T= -.0228  XC=  .4416  YC=  .6739
Z=  .4978 CONS  .0010  R= 1.0315  B2= 4.0995  G=  .0550  T= -.0226  XC=  .5707  YC=  .8933
Z=  .4983 CONS  .0010  R= 1.4694  B2= 4.1247  G=  .0575  T= -.0225  XC=  .7922  YC= 1.2725
Z=  .4982 CONS  .0010  R= 2.4051  B2= 4.1488  G=  .0600  T= -.0223  XC= 1.2626  YC= 2.0829
Z=  .5022 CONS  .0009  R= 5.7157  B2= 4.1716  G=  .0625  T= -.0222  XC= 2.9203  YC= 4.9499
Z=  .4976 CONS  .0010  R=  .0652  B2= 2.3999  G=  .0650  T=  .0495  XC=  .0976  YC=  .0564
Z=  .4978 CONS  .0010  R=  .0571  B2= 2.4078  G=  .0675  T=  .0537  XC=  .0960  YC=  .0494
Z=  .4978 CONS  .0010  R=  .0515  B2= 2.4284  G=  .0700  T=  .0568  XC=  .0957  YC=  .0446
Z=  .4978 CONS  .0010  R=  .0475  B2= 2.4581  G=  .0725  T=  .0594  XC=  .0962  YC=  .0411
Z=  .4980 CONS  .0010  R=  .0447  B2= 2.4962  G=  .0750  T=  .0616  XC=  .0974  YC=  .0387
Z=  .5025 CONS  .0010  R=  .1109  B2= 2.7010  G=  .0775  T=  .0326  XC=  .1330  YC=  .0961
Z=  .4999 CONS  .0010  R=  .1145  B2= 2.7370  G=  .0800  T=  .0320  XC=  .1373  YC=  .0992
Z=  .5008 CONS  .0010  R=  .1180  B2= 2.7713  G=  .0825  T=  .0315  XC=  .1415  YC=  .1022
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Z=	.4996	CONS	.0010	R=	.1216	B2=	2.8050	G=	.0850	T=	.0310	XC=	.1458	YC=	.1053
Z=	.4980	CONS	.0010	R=	.0433	B2=	2.7786	G=	.0875	T=	.0687	XC=	.1092	YC=	.0375
Z=	.4999	CONS	.0010	R=	.0449	B2=	2.8465	G=	.0900	T=	.0695	XC=	.1125	YC=	.0389
Z=	.4977	CONS	.0010	R=	.0470	B2=	2.9146	G=	.0925	T=	.0702	XC=	.1160	YC=	.0407
Z=	.4975	CONS	.0010	R=	.0495	B2=	2.9833	G=	.0950	T=	.0709	XC=	.1198	YC=	.0429
Z=	.5005	CONS	.0010	R=	.0526	B2=	3.0521	G=	.0975	T=	.0714	XC=	.1238	YC=	.0456