Method to increase uniformity in horizontal CVD reactors

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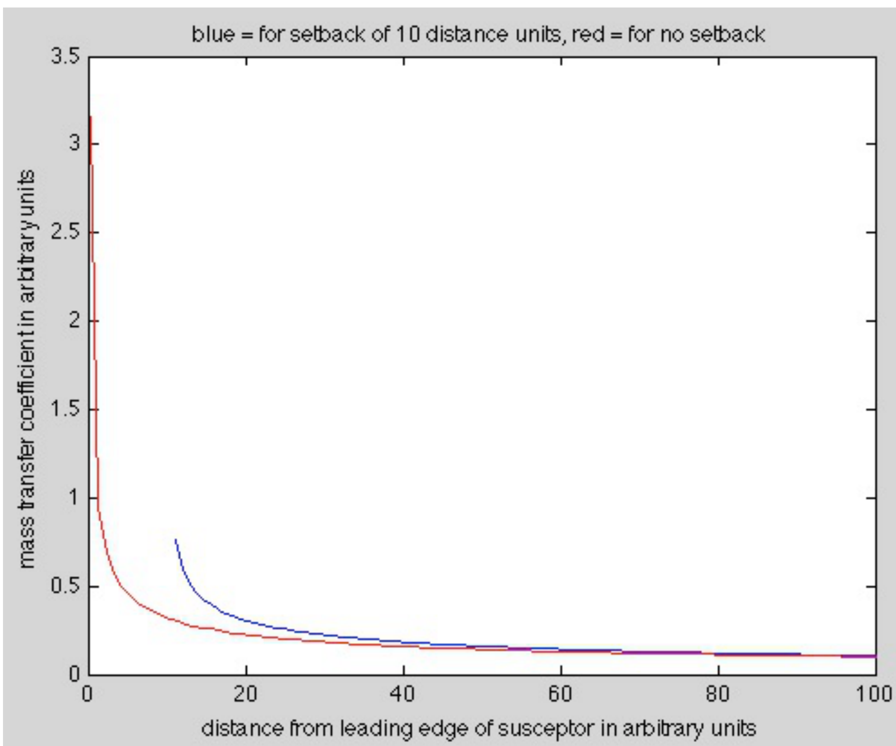
Consider an isothermal CVD system with wafers on a susceptor surface and the first wafer edge located at the leading edge of the susceptor. Note that we are neglecting temperature effects here to keep things simple, but temperature effects will be significant in the design of a real CVD reactor.

The mass transfer coefficient is infinite at the leading edge and then decreases proportional to the square-root of the distance from the leading edge. For mass-transfer limited surface reaction, the reaction rate at the leading edge will be equal to the rate at the bulk, free-stream concentration (not infinite) and then decreases proportional to the square-root of the distance from the leading edge.

There are two ways we will consider to try to make the reaction rate more uniform, i.e., vary with distance to a power lower than 1/2.

1) Wafer setback from leading edge

First, what would happen if we were to move the first wafer back from the leading edge of the wafer? The mass transfer solution is analogous to the heat transfer solution provided by Burmeister (1993, pp. 237-240). Here is a plot of how the mass transfer coefficient would vary with distance.



Say that the wafer diameter is 10 units. The blue line is for reaction with the first wafer setback by one wafer diameter from the leading edge. There is still substantial variation in the mass transfer coefficient over the first wafer, although that variation is less than over a wafer with no setback.

What do you think? What about putting one blank (unpatterned) but reactive wafer with no setback from the leading edge, followed by the wafers being patterned? That looks like it would give more uniform deposition than having the first reactive wafer setback from the leading edge.

Listing of Matlab program that produced the plot above.

```
% CVD with wafers setback from
% leading edge of susceptor.
% See Burmeister, "Convective Heat Transfer,"
% 2nd ed., Wiley (1993), pp. 237-240
% for heat transfer for laminar boundary
% layer with unheated starting length.
% Mass transfer solution is similar to heat transfer solution.
% Nu(m) = Sh = h(c)*x/D ; Re = U*x/nu ; Sc = nu/D
% Sh = 0.332*Sc^(1/3)*Re^(1/2) for no setback
% h(c) proportional to x^(1/2)/x for no setback
% Burmeister uses integral method to solve for case with setback
clear

% CASE WITH SETBACK
% hx is x-dependence of mass transfer coefficient
% for wafers setback X0 distance units
X0 = 10;
x = linspace(X0,10*X0,100);
hx = x.^0.5./x./(1-(X0./x).^0.75).^(1/3);

% CASE WITH NO SETBACK
% hx2 is x-dependence of mass transfer coefficient
% for wafers with no setback
x2 = linspace(0.01*X0,10*X0,100);
hx2 = x2.^0.5./x2;

plot(x,hx,'b',x2,hx2,'r')
title('blue = for setback of 10 distance units, red = for no setback')
ylabel('mass transfer coefficient in arbitrary units')
xlabel('distance from leading edge of susceptor in arbitrary units')
```

2) Slanted susceptor

Now consider a wedge-shaped susceptor whose surface height increases linearly with distance down the reactor. This provides a component of gas flow normal to the surface that should enhance mass transfer of reactant to the surface.

Model the slanted susceptor as one-half of a semi-infinite full wedge whose point faces into the flowing gas. The angle of the full wedge is $\beta\pi$ radians and the centerline of the full wedge is parallel to the flow direction of the freestream gas. The coordinate *x* is parallel to the wedge surface, and the coordinate *y* is normal to the wedge surface. Burmeister (1993, pp. 186-196) discusses the heat transfer solution for this case.

The parameter *m* is defined in terms of the angle and potential (inviscid) theory shows how the freestream velocity over the wedge surface varies with *x*.

$$m = \frac{\beta}{2-\beta} \qquad U = C x^m$$

The definitions of the similarity variable and the stream function are now functions of *m*.

$$\eta = y\left(\frac{U}{\nu x}\right)^{1/2} = y\left(\frac{C}{\nu}\right)^{1/2} x^{(m-1)/2}$$

$$\psi = (\nu U x)^{1/2} F(\eta) = (\nu C x^{m+1})^{1/2} F(\eta)$$

Be careful, other authors use (*y*/2) in place of (*y*) in the similarity variable definition. This difference just changes a coefficient here and there but not the functional dependence of heat and mass transfer coefficients on *x*.

Instead of the Blasius equation for free-stream flow that is parallel to the surface, we get the Falkner-Skan equation.

$$F''' + \left(\frac{m+1}{2}\right) F F'' + m\left[1 - (F')^2\right] = 0$$

The boundary layer thickness variation with *x* now depends on the wedge angle.

$$\delta \propto x^{(1-m)/2}$$

This solution is for the velocity boundary layer. Assume that the mass transfer (concentration) boundary layer has the same dependence on *x* and *m*. The mass transfer coefficient is proportional to the inverse of the boundary layer thickness.

$$h_c \propto \frac{1}{x^{(1-m)/2}}$$

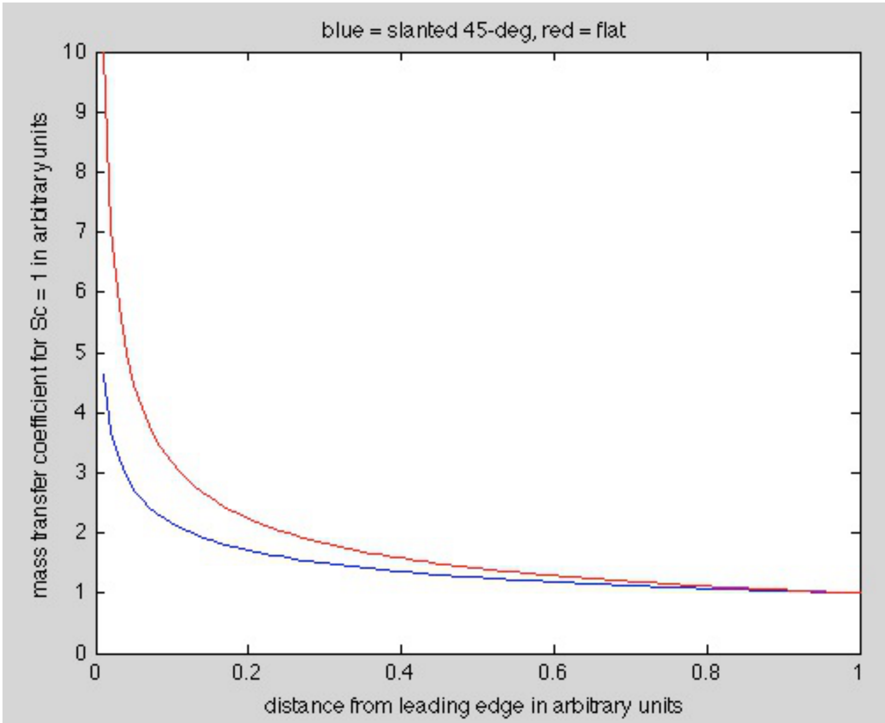
A full wedge angle of 90° = $\pi/2$ radians gives $m = 1/3$. This is for a susceptor that slants upwards at 45° from the horizontal surface of the reactor. The mass transfer coefficient varies with the 1/3-rd power of *x*, rather than the 1/2 power for a horizontal surface. See plot on the next page. This helps.

Matlab listing

```
x = linspace(0.01,1,100);
m = 1/3;
h = 1./x.^((1-m)/2);
plot(x,h)
h2 = 1./x.^0.5;
plot(x,h,'b',x,h2,'r')
title('blue = slanted 45-deg, red = flat')
ylabel('mass transfer coefficient for Sc = 1 in arbitrary units')
xlabel('distance from leading edge in arbitrary units')
axis([0 1 0 10])
```

References

Burmeister, L. C., Convective Heat Transfer, 2nd ed., John Wiley & Sons (1993).


blue = slanted 45-deg, red = flat
mass transfer coefficient for Sc = 1 in arbitrary units
distance from leading edge in arbitrary units
10
9
8
7
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1