CBE 40445

9/30/20

FURTHER EXAMINATION OF MASS TRANSFER RESISTANCE IN HETEROGENEOUS CATALYSIS

- COMBINED EXTERNAL INTERNAL RESISTANCE FROM A "THEORETICAL" PERSPECTIVE

- EFFECT OF MASS TRANSFER RESISTANCE ON OBSERVED KINETICS

BUT FIRST A TOPIC THAT I ENCOUNTERED (AGAIN)

ORIGININAL (ANTIGENIC) SIN

→ POTENTIAL THAT A PREVIOUS ENCOUNTER WITH A PATHOGEN AFFECTS YOUR IMMUNESYSTEM IN SUCH A WAY AS TO <u>REDUCE</u> YOUR ABILITY TO FIGHT THE NEXT PATHOGEN

— CURRENT ISSUE, WOULD THE LATEST FLU VACCINE DO THIS RE COVID-19 ??

NO EVIDENCE OF THIS !!

Antibody Dependent Enhancement Due to Original Antigenic Sin and the Development of SARS

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Abstract

Human coronavirus (HCoV) is one of the most common causes of respiratory tract infections throughout the world. Two phenomena observed so far in the development of the SARS-CoV-2 pandemic deserve further attention. First, the relative absence of clinical signs of infections in children, second, the early appearance of IgG in certain patients. From the point of view of immune system physiology, such an early rise of specific IgG is expected in secondary immune responses when memory to a cross-reactive antigen is present, usually from an earlier infection with a coronavirus. It is actually typical for the immune system to respond, to what it already knows, a phenomenon that has been observed in many infections with closely related viruses and has been termed "original antigenic sin." The question then arises whether such cross-reactive antibodies are protective or not against the new virus. The worst scenario would be when such cross-reactive memory antibodies to related coronaviruses would not only be non-protective but even enhance infection and the clinical course. Such a phenomenon of antibody dependent enhancement (ADE) has already been described in several viral infections. Thus, the development of IgG against SARS-CoV-2 in the course of COVID-19 might not be a simple sign of viral clearance and developing protection against the virus. On the contrary, due to cross-reaction to related coronavirus strains from earlier infections, in certain patients IgG might enhance clinical progression due to ADE. The patient's viral history of coronavirus infection might be crucial to the development of the current infection with SARS-CoV-2. Furthermore, it poses a note of caution when treating COVID-19 patients with convalescent sera.

WHY SOME PEOPLE GET REALLY SICK

A Novel Hypothesis for Original Antigenic Sin in the Severe Disease of SARS-CoV-2 Infection

Heinz Kohler and Peter Nara

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Abstract

In this hypothesis, we address the biological/immunological pathway leading to severe disease or death after infection with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The underlying immune response is described with "original antigenic sin" (OAS) whereby previous infections influence the response to future virus encounters. We cite evidence for OAS-induced immunopathology in HIV-1 disease. We hypothesize that similar immune abnormalities can occur after infection with SARS-CoV-2. This hypothesis is supported by recent analysis of the antibodies in infected patients demonstrating serological and B cell abnormalities. The concept of symmetrical clonal regulation developed earlier for the immune network illustrates the pathway suggested by our hypothesis and may be helpful to develop strategies avoiding severe coronavirus disease 2019.

Individualizing Risk Prediction for Positive Coronavirus Disease 2019 Testing

Results from 11,672 Patients

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In the development cohort, 11,672 patients fulfilled study criteria, including 818 patients (7.0%) who tested positive for COVID-19; in the validation cohort, 2295 patients fulfilled criteria, including 290 patients who tested positive for COVID-19. Male, African American, older patients, and those with known COVID-19 exposure were at higher risk of being positive for COVID-19. Risk was reduced in those who had pneumococcal polysaccharide or influenza vaccine or who were on melatonin, paroxetine, or carvedilol. Our model had favorable discrimination (c-statistic = 0.863 in the development cohort and 0.840 in the validation cohort) and calibration. We present sensitivity, specificity, negative predictive value, and positive predictive value at different prediction cutoff points. The calculator is freely available at https://riskcalc.org/COVID19.

FLU SHOT REDUCED COVID-19 CASES

DOES THIS GENERALIZE?

SORTING OUT SUCH QUESTIONS: SYSTEMS ENGINEERING

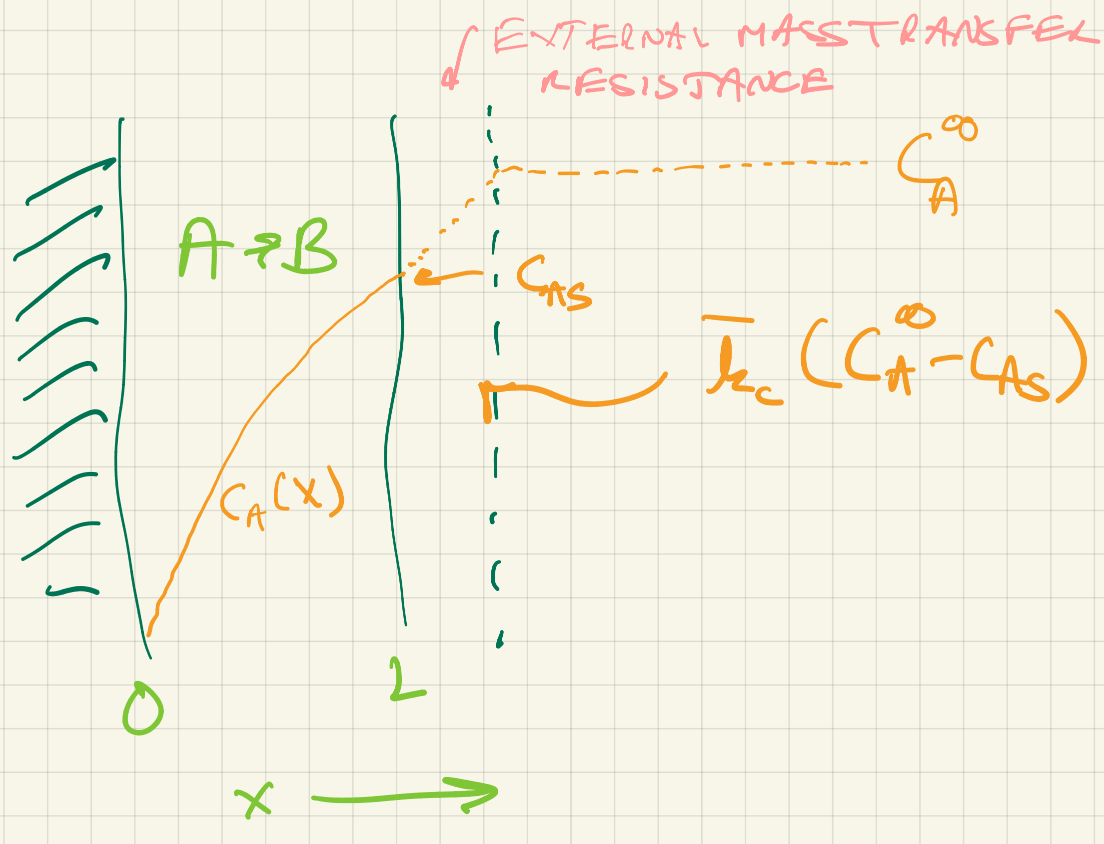
EXAMINATION OF COMBINED EXTERNAL + INTERNAL RESISTANCE FROM SOLUTIONS TO "EXACT" EQUATIONS

CONSIDER 1ST ORDER REACTION

SLAB GEOMETRY

$$A \longrightarrow B$$

$$r = k C_A$$



$$0 = D_{TA}^{\circ} \cdot \frac{\partial^2 C_A}{\partial x^2} - k C_A$$

SOLVE INSIDE PELLET WITH A BOUNDARY CONDITION THAT ACCOUNTS FOR EXTERNAL MASS TRANSFER

$$\eta \equiv \frac{x}{L} \quad (0 - 1)$$

$$\Theta \equiv \frac{C_A}{C_A^{\infty}}$$

$$\phi^2 \equiv \frac{k L}{D_{TA}^{\circ}}$$

REACTION RATE CONSTANT

$$Bi \equiv \frac{L \bar{k}_c}{D_{TA}}$$

MASS TRANSFER COEFFICIENT

$$0 = \frac{d^2\theta}{d\eta^2} - \phi^2\theta$$

$$\left.\frac{\partial\theta}{\partial\eta}\right|_{\eta=1} = -Bi\left(\theta(1) - 1\right)$$

FLUX INSIDE PELLET = FLUX TO SURFACE OF PELLET

$$\theta'(\eta=0) = 0$$

NO FLUX PAST THE "BOUNDARY"

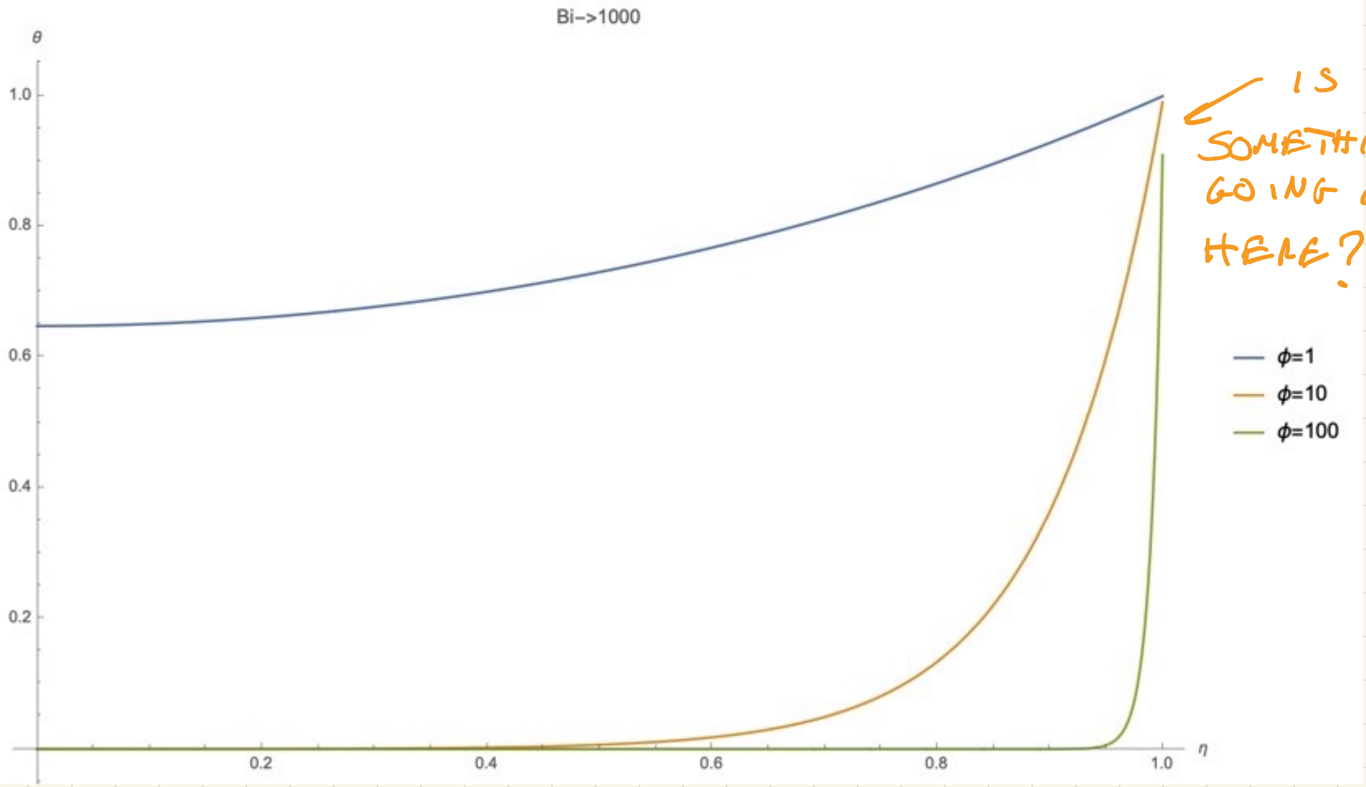
FOR A CYLIDER OR SPHERE, THIS IS A SYMMETRY CONDITION ACROSS $r=0$

$$\theta(\eta) = \frac{Bi\,\cosh(\eta\phi)}{Bi\,\cosh(\phi) + \phi\,\sinh(\phi)}$$

FOR $Bi = 1000$ $Bi \equiv \frac{L \bar{k}_c}{D_{TA}}$

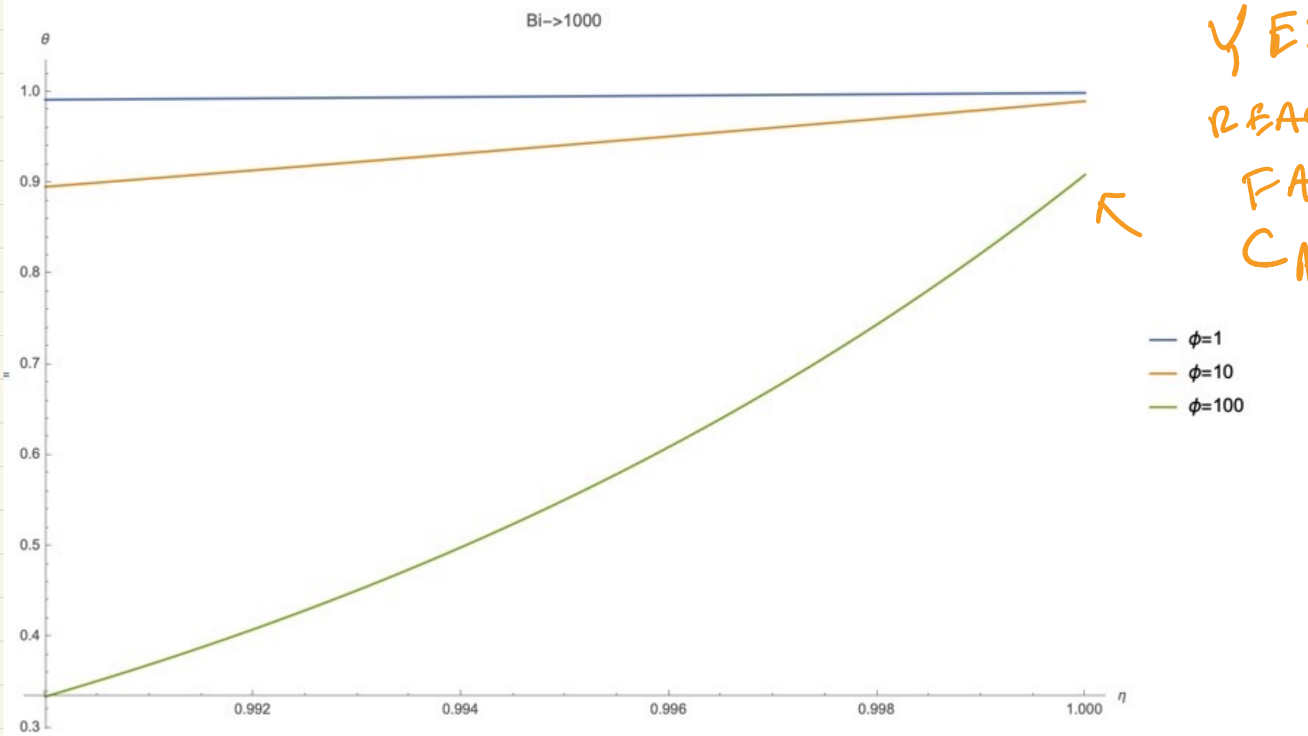
EXTERNAL MASS TRANSFER IS NOT LIMITING UNTIL VERY HIGH REACTION RATES

```
bianswerplot = Plot[{ans /. {ϕ → 1, Bi → 1000}, ans /. {ϕ → 10, Bi → 1000}, ans /. {ϕ → 100, Bi → 1000}}, {η, 0, 1},
  AxesLabel → {"η", "θ"}, PlotRange → All, PlotLegends → {"ϕ=1", "ϕ=10", "ϕ=100"}, PlotLabel → "Bi->1000"]
```



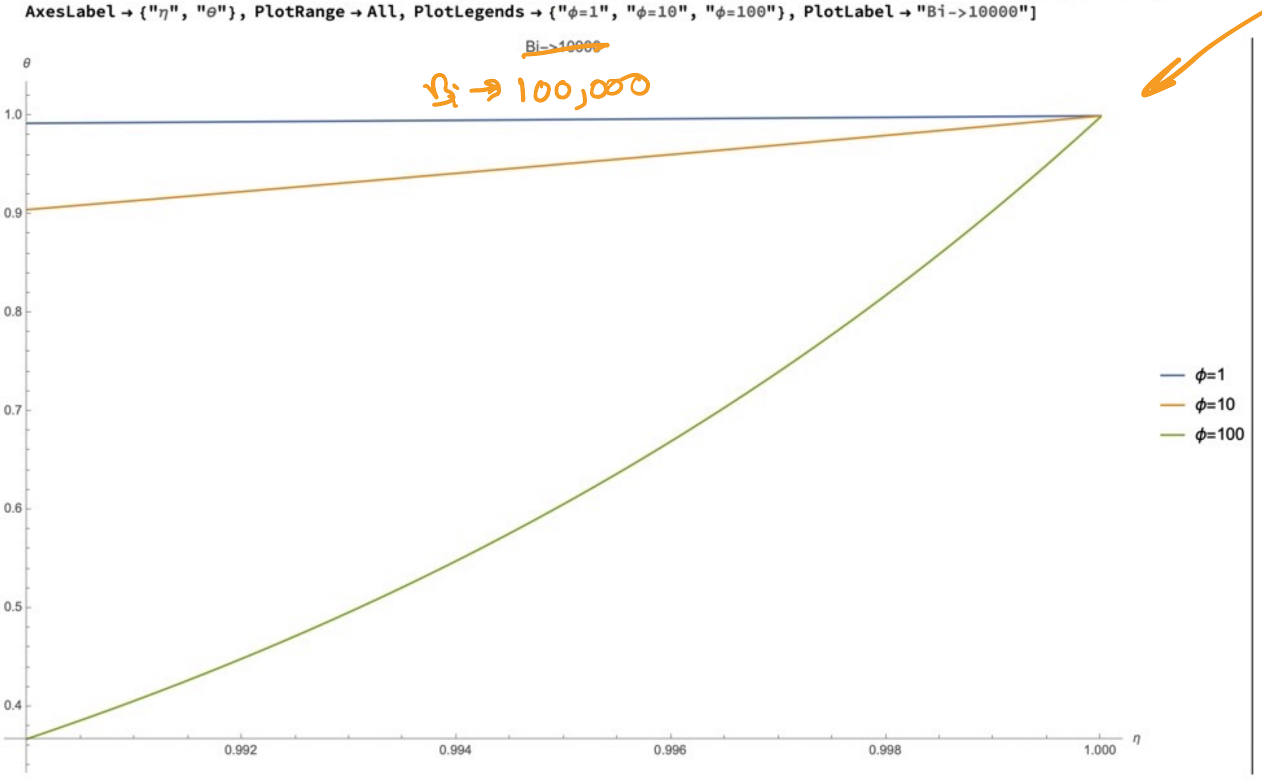
IS SOMETHING GOING ON HERE?

```
bianswerplot95 = Plot[{ans /. {ϕ → 1, Bi → 1000}, ans /. {ϕ → 10, Bi → 1000}, ans /. {ϕ → 100, Bi → 1000}}, {η, .99, 1},
  AxesLabel → {"η", "θ"}, PlotRange → All, PlotLegends → {"ϕ=1", "ϕ=10", "ϕ=100"}, PlotLabel → "Bi->1000"]
```



YES, IF REACTION IS FAST $C_{AS} < 1$

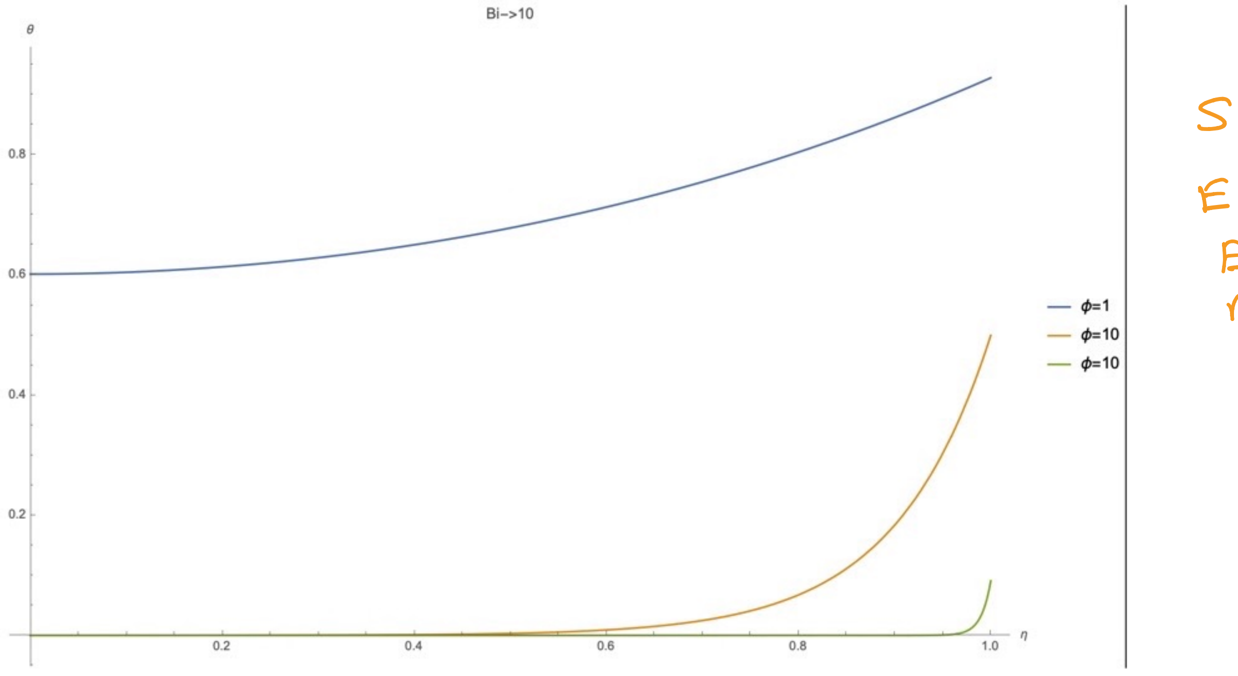
```
bianswerplot2 = Plot[{ans /. {ϕ → 1, Bi → 100 000}, ans /. {ϕ → 10, Bi → 100 000}, ans /. {ϕ → 100, Bi → 100 000}}, {η, .99, 1},
  AxesLabel → {"η", "θ"}, PlotRange → All, PlotLegends → {"ϕ=1", "ϕ=10", "ϕ=100"}, PlotLabel → "Bi->10000"]
```



AT $Bi = 100{,}000$ WE GET $C_{AS} = 1$

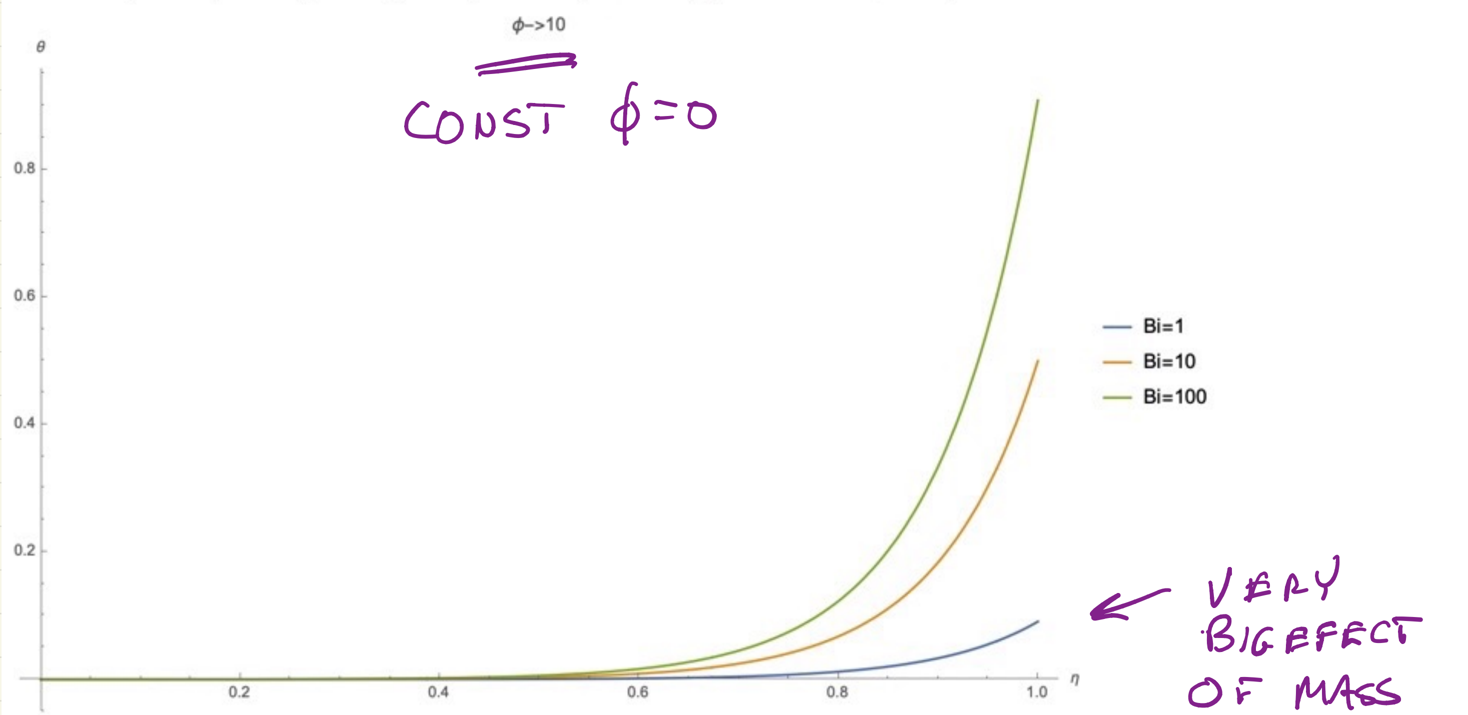
A MORE MODERATE Bi

```
bianswerplot10 = Plot[{ans /. {ϕ → 1, Bi → 10}, ans /. {ϕ → 10, Bi → 10}, ans /. {ϕ → 100, Bi → 10}}, {η, 0, 1}, AxesLabel → {"η", "θ"},
  PlotRange → All, PlotLegends → {"ϕ=1", "ϕ=10", "ϕ=10"}, PlotLabel → "Bi->10"]
```



SUBSTANTIAL EFFECT OF EXTERNAL RESISTANCE

```
bianswerplot = Plot[{ans /. {ϕ → 10, Bi → 1}, ans /. {ϕ → 10, Bi → 10}, ans /. {ϕ → 10, Bi → 100}}, {η, 0, 1}, AxesLabel → {"η", "θ"},
  PlotRange → All, PlotLegends → {"Bi=1", "Bi=10", "Bi=100"}, PlotLabel → "ϕ->10"]
```



← VERY BIG EFFECT OF MASS TRANSFER RESISTANCE

WHAT IS FLUX TO SURFACE

$$\left.\frac{\partial \theta}{\partial \eta}\right|_{\eta=1} = \frac{Bi\, \phi \sinh(\phi)}{Bi \cosh(\phi) + \phi \sinh(\phi)}$$

THIS IS A FAMILAR FORM

IF $\phi \gg 1$ FLUX $\rightarrow Bi$

$\theta(1) = 0$, $(C_s = 0)$

MASS TRANSFER IS CONTROLLING

IF $Bi \rightarrow \infty$

FLUX $= \phi \tanh \phi$

OR

$$\eta = \frac{\text{FLUX}}{\phi^2} = \frac{\tanh \phi}{\phi}$$

SAME RESULT AS BEFORE

MORE GENERALLY

$$\eta = \frac{\left.\frac{\partial \psi}{\partial \eta}\right|_{\eta=1}}{\phi^2} = \frac{Bi}{\phi^2 + Bi \coth\phi}$$

$$= \frac{\tanh\phi}{\phi\left(1 + \frac{\phi\tanh\phi}{Bi}\right)}$$

WHAT DOES THIS SAY ABOUT REACTION RATE

$D^e_{JA} \frac{\partial C_A}{\partial x} \Longrightarrow$ RATE OF C_A GOING INTO CATALYST

$$\left.\frac{\partial \theta}{\partial \eta}\right|_{\eta=1} = \frac{Bi\,\phi\,\sinh(\phi)}{Bi\cosh(\phi) + \phi\sinh(\phi)}$$

MAKE DIMENSIONAL :

$$D_{TA}^{e}\frac{dC_A}{dx} = \frac{C^\infty}{L} D_{TA}\frac{\partial\theta}{\partial \eta} =$$

$$= \frac{\bar{k}_c C^{\infty}}{1+\frac{\bar{k}_c}{kL}\coth\left[\frac{kL^2}{D_{TA}^e}\right]}$$

$Lk >> k_c$

$$\text{FLUX} = \bar{k}_c C^\infty$$

JUST EXTERNAL MASS TRANSFER

$k_c >> Lk$

$$\text{FLUX} = k C^\infty L \tanh\left[\frac{kL^2}{D_{TA}}\right]$$

YOU CAN PHYSICALLY REDUCE EXTERNAL MASS TRANSFER RESISTANCE BY "STIRRING FASTER"

$$Sh = 2 + 0.6\, Re^{1/2}\, Sc^{1/3}$$

USUALLY MASS TRANSFER HAS LIMITED RANGE ~ FACTOR ~ 5-10

SO OTHERWISE TO REDUCE EFFECT OF $\bar{\eta}_c$,

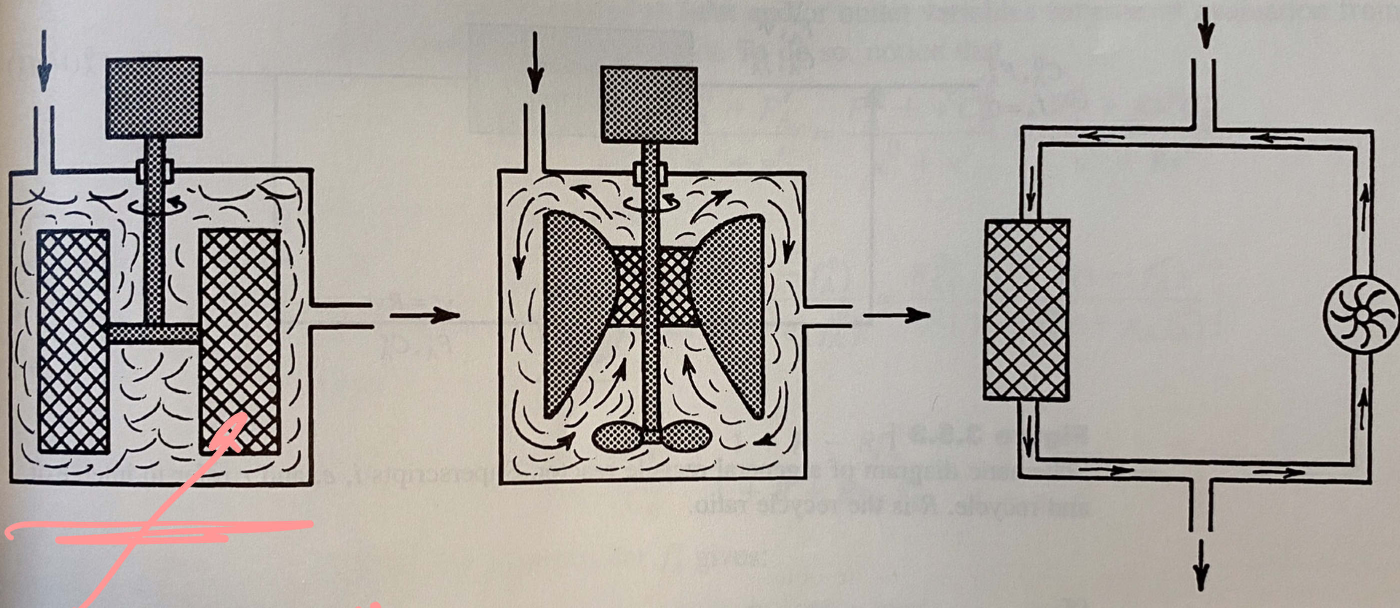
SMALLER L, (R_p)

SMALLER k, LOWER CATALYST LOADING, LOWER TEMP

ANALYSIS OF RATE DATA FOR SITUATIONS WHERE MASS TRANSFER RESISTANCE COULD BE IMPORTANT

- STIRRING SPEED —

- PARTICLE SIZE –



(a) (b) (c)

Figure 3.5.2 |
Stirred contained solids reactors. [Reproduced from V. W. Weekman, Jr., *AIChE J.*, **20** (1974) p. 835, with permission of the American Institute of Chemical Engineers. Copyright © 1974 AIChE. All rights reserved.] **(a)** Carberry reactor, **(b)** Berty reactor (internal recycle reactor), **(c)** external recycle reactor.

CATALYST IN "BASKET" THAT IS STIRRED FOR GOOD MASS TRANSFER

$Sh = 2 + 0.6\, Re^{1/2}\, Sc^{1/3}$

FACTOR OF 3

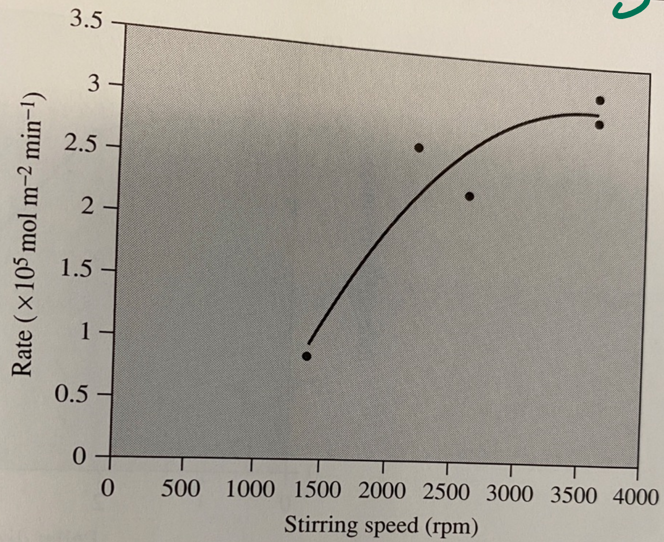


Figure 6.5.1 |
Effect of agitation on the rate of 2-propanol dehydrogenation to acetone at 355 K over Ni catalysts. [Rates are calculated at constant conversion level from the data in D. E. Mears and M. Boudart, *AIChE J.*, **12** (1966) 313.] In this case, increasing the stirring speed increased the rate of acetone diffusion away from the catalyst pellet and decreased product inhibition.

...lems are encountered in a catalytic reac

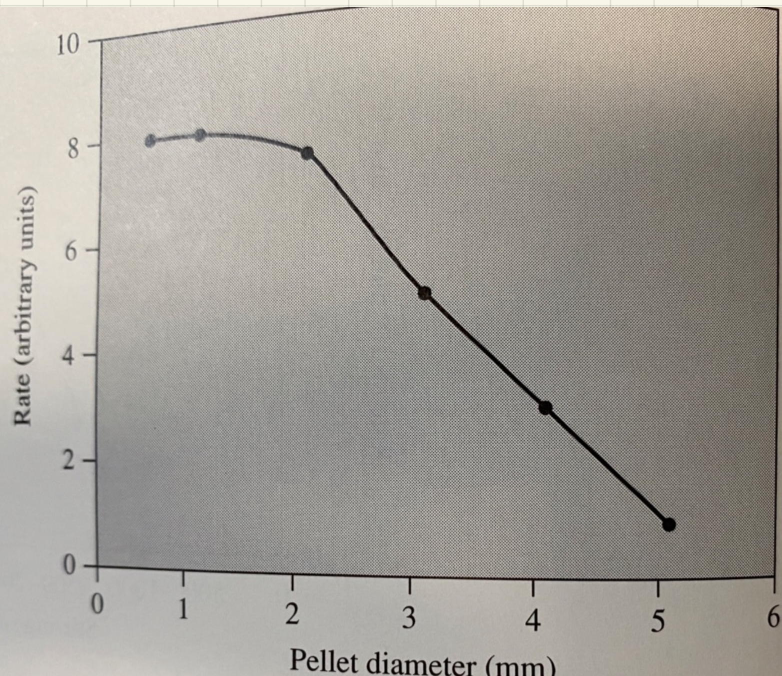


Figure 6.5.2 |
Schematic illustration of the influence of catalyst pellet size on the observed reaction rate.

CAN REDUCE BOTH EXTERNAL + INTERNAL RESISTANCE

RULES OF THUMB

(IN TERMS OF OBSERVED RATE)

INTERNAL MASS TRANSFER NOT LIMITING:

$$\frac{r_{obs} R_p^2}{D_{TA}^e C_{AS}} < 1$$

n ORDER:

$$\frac{r_{obs} R_p^2}{D_{TA}^e C_{AS}} < \frac{1}{n}$$

EXTERNAL RESISTANCE NOT LIMITING!

$$\frac{r_{obs} R_p^2}{\bar{k}_c C_{AB}} < \frac{.15}{n}$$

CAN ALSO CONSIDER HEAT TRANSFER LIMITATIONS

INTERPHASE

$$\frac{\Delta H_r \, r_{obs} \, R_p}{h_t \, T_B} < 0.15 \frac{R_G T_B}{E}$$

INTERNAL TO PARTICLE

$$\frac{\Delta H_r \, r_{obs} \, R_p}{\lambda^e \, T_s} < .75 \frac{R_G T_s}{E}$$