

The Chemical  
Reactor  
Omnibook

Levenspiel

THE  
CHEMICAL  
REACTOR  
OMNIBOOK

A handwritten signature in black ink, reading "Octave Levenspiel". The signature is fluid and cursive, with a large initial "O" and a stylized "X" at the end.

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Amel S. 1/2

## PREFACE

Start with a collection of practice exercises, add some key formulas, mix in problems from experience, and sprinkle with paragraphs of explanation: if you wander all over the subject like that, not having the good sense to know when to stop, you end up with an OMNIBOOK. That's what happened here.

What is it good for? Perhaps

- a reference book for methods in reactor design
- a supplementary text for a course of study
- the basis for a self paced or self study course on the subject

I firmly believe that learning comes with doing, and with trying to apply ideas to new situations. Hence this book focuses on solving problems. Try them and if you have trouble then go to the text for help. I have kept the problems very simple to emphasize principles. Most are solved in a page or less.

Regarding the text: I should warn the reader that despite its length the Omnibook's presentation is rather condensed. In most cases, I have avoided details of derivations and have jumped from assumptions or starting points directly to the final useful expressions. This compactness is particularly evident in the first few chapters.

A while back when my first book went to press I was confident that it was free from error, just perfect. Now 400+ errors later I know better. So dear reader, if you question my reasoning (and there are quite a number of original analyses in this book) or if you find errors, whether big or small, let me know. I would much appreciate it.

Many have contributed one way or other to this work. First and foremost my thanks go to the many many senior and graduate students in my classes who helped in so many ways—derivations, design charts, catching errors, etc. In particular I would like to recognize:

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Then colleagues in the Department and elsewhere who helped me whenever I got stuck, which was too often:

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There is no forgetting Clover Redfern, Polly Eubanks, Kris Thomsen and Connie Chapman who so carefully transferred problems from scrawl to type. And to American Meter Co., division of Singer Corporation (the sewing machine people) my gratitude for letting me use their delightful Searle cartoon. Who would have thought that Ronald Searle of cat fame was really a reactor man? Finally a medal for Mary Jo, my wife, for all her help and encouragement in this project. I hope that she will now let me use the word Omnibook in Scrabble.

I'd like to dedicate this book to my father, Abe, a real engineer; and to my mother, Lily, indescribable.

A handwritten signature in cursive script that reads "Octave Levenspiel". The signature is written in dark ink and is positioned in the lower right quadrant of the page.

Corvallis, Oregon  
May 1979

## EXPLANATORY NOTES

**Basic Philosophy:** One can approach the characterization of chemical reactors at different levels of sophistication, accuracy and complexity. I have always had a soft spot for the simple model since it is easily solved, usually gives the main features of the process, and a feel for what is happening. Of course the simple model can always be refined and extended when needed. If its extension gives a very different answer, this is a warning to look into the matter more carefully. Albert Einstein put it nicely, and he could have been looking straight at me, when he said, "Everything should be made as simple as possible, but not simpler."

In general, I have tried to avoid complex material and methods in the Omnibook since there are so many important elementary ideas to treat on the subject.

**Teaching from the Omnibook:** Some of this material may be suitable for a first course on reactors, the rest for advanced courses. Here's a suggestion.

1. For a broad background course, which is what I feel a first course on the subject should be, cover chapters 1, 2, 3, 4, 5 to pg 8, 11, 21, 23 to pg 6, 24 to pg 14, 51, 52 to pg 4, 61, 62. For those who want this material alone, it is available in a slim volume as "The Chemical Reactor Minibook."

After this introduction one can cover the remaining material in any order desired, for example:

2. Gas solids systems: chapters 22, 25, 30's, 50's
3. Chapters 40's, 60's, 80's
4. Chapters 6, 7, 8, 9, the rest of 23, 24, 70's, 90's, etc.

**A self paced first course:** A number of teachers, and I too, have taught a self paced course using the Omnibook in its preliminary form plus (sometimes) a text book to fill out. Each teacher has his own way of doing it. This is how I have tried it.

- (a) The student is told that completing twelve chapters means an A; seven chapters, a bare pass, and so on.
- (b) The student studies a particular chapter, tries a few problems, and when he feels ready he takes a test. This involves doing two problems chosen by me from the end of the chapter. If he passes he goes on to the next chapter. If not, he tries again.
- (c) The tests are offered two or three times a week.
- (d) I am available as consultant, to help the student. My aim is not to trick him but to help him learn the material and pass the tests. Of course the student can guarantee a pass by doing all the problems at the end of the chapter.
- (e) Once a week I give a general lecture on the main ideas on the subject, historical highlights, interesting industrial experiences, etc.

Students like this approach because they know beforehand exactly what is required of them, and they can pace themselves accordingly. For me, the teacher, unhappily, it means much more work. Also, I have an uncomfortable feeling that the student may not retain as much with this type of course because he focuses too narrowly on his immediate hurdle. A careful follow-up would tell is this is so.

**Problems:** A few words about these since they form such a large part of the Omnibook. First of all let me say that they involve no tricks, all are solvable by the methods and equations in the text (in fact, frequently the problems came first, then the text was prepared as accompaniment), most are short, few needing more than one page to solve.

Problems are grouped according to type by the letters A, B, C,...; problems Z are only for discussion; \* designate harder problems; \*\* are longer ones, usually unsuited for quizzes.

In learning the material it is a good idea to try one problem of each type.

**References:** The following books are referred to compactly by the authors' names or by the underlined words.

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## CONTENTS

Explanatory Notes

### SINGLE PHASE REACTORS

<b>1. Introduction to single phase reactors</b>	
Some simple reactor types	1.2
The rate equation	1.3
Nomenclature, and an example problem	1.5
Converting pressures to concentrations, and an example	1.10
68 problems	after 1.11
<b>2. The batch reactor</b>	
Basic performance equation	2.1
Integrated forms for constant volume	2.2
Integrated forms for constant pressure, changing volume	2.6
Comments	2.7
58 problems	after 2.7
<b>3. The plug flow reactor</b>	
Basic performance equation	3.1
Integrated forms	3.2
Comments	3.3
Example	3.4
90 problems	after 3.5
<b>4. The mixed flow reactor</b>	
Basic performance equation	4.1
Particular forms of the performance equation	4.2
Comments	4.3
87 problems	after 4.4
<b>5. More on ideal reactors, and extensions</b>	
Recycle reactor	5.1
Comparison of single reactors	5.4
Mixed flow reactors in series	5.5
Any combination of reactors	5.6
Finding the best combination of reactors	5.7
Other contacting patterns	5.8
Simple economic problems	5.9
88 problems	after 5.12
<b>6. Multiple reactions: qualitative</b>	
Rule 1: on desirable operating temperatures	6.2
Rule 2: on concentration levels	6.2
Rule 3: on maximizing the production of an intermediate	6.3
Rule 4: on series—parallel reactions	6.4
Rule 5: on optimization in the face of physical restraint	6.6
Comments	6.7
94 problems	after 6.8

<b>7. One step reactions: parallel, side-by-side, etc.</b>	
Single reactant systems	7.1
Fractional yield, performance expression, best reactor type	
Two reactant systems	7.5
Fractional yield, contacting patterns, side entry reactors	
Side by side reactions	7.8
45 problems	after 7.8

## INTERLUDE

<b>11. Multiphase reactors, background discussion</b>	
Kinetics and six examples	11.1
The general performance equation	11.5
Simplifications leading to practical expressions	11.7
Simple contacting models, reduction to one phase systems, final thoughts on flow modeling	
24 problems	after 11.10

## REACTORS WITH SOLID CATALYST

<b>21. Introduction to solid catalysed reactions</b>	
Definition of reaction rate	21.2
Performance equations	21.3
Simultaneous homogeneous and heterogeneous reactions	21.4
Types of experimental reactors	21.4
Reflections	21.5
69 problems	after 21.6
<b>22. The porous catalyst pellet</b>	
The spectrum of kinetic regimes	22.1
Rate equation for each regime	22.2
Surface kinetics, pore diffusion, temperature gradients within the particle and in the gas film, film mass transfer limitations	
Effectiveness factor for all regimes	22.11
Interpreting data and predicting behavior	22.12
Final thoughts	22.18
38 problems	after 22.18
<b>23. Pore diffusion effects in reactors</b>	
Single irreversible first order reaction	23.1
Single reaction other than first order irreversible	23.4
Multiple reactions: the shift in product distribution	23.7
Particles having more than one pore size	23.9
Final comments	23.12
57 problems	after 23.12
<b>24. Adiabatic packed bed reactors</b>	
Graphical representation	24.1
Design for single stage reactors	24.3

Design for multistage reactors	24.7
Plug, mixed and recycle flow; cooling with cold feed or cold inert gas; best type of reactor to use; about heat exchangers, endothermic reactions	
The hot spot and temperature runaway	24.15
Reactors with internal cooling, and with large recycle of gas	
60 problems	after 24.20
<b>25. Fluidized reactors of fine catalyst solids</b>	
The single rising bubble	25.3
Flow model for beds of fine particles	25.4
Application to catalytic reactions	25.7
First order reaction and example, Denbigh reaction and example	
Discussion	25.18
Extension of flow model, internals, slugging beds, large particle beds, the fast fluidized bed, suppression of bubbles	
18 problems	after 25.20
<b>CATALYTIC REACTORS WITH TWO CHANGING PHASES</b>	
<b>31. Kinetics of deactivating porous catalyst pellets</b>	
Rate forms	31.1
Experimental devices and strategy	31.2
Finding the rate from batch S/flow G experiments	31.4
Finding the rate from batch S/batch G experiments	31.13
Distortion of rate by pore diffusion	31.16
20 problems	after 31.18
<b>32. Reactors with a batch of slowly deactivating catalyst</b>	
Batch S/once through G reactors	32.2
Reactors with recycle of unused reactant	32.14
Batch mixed S/batch mixed G reactors	32.19
26 problems	after 32.19
<b>33. Reactors with flowing deactivating catalyst</b>	
Concentration independent deactivation	33.1
Single reactors and reactor-regenerators	
Concentration dependent deactivation	33.5
Deactivation in fluidized beds	33.6
Optimum size ratio of reactor-regenerators	33.7
34 problems	after 33.8
<b>34. G/L reactions on solid catalyst: trickle beds, slurry reactors, 3 phase fluidized beds</b>	
General rate equation	34.2
Simplifications	34.4
Performance equation for an excess of liquid reactant	34.6
Performance equation for an excess of gas reactant	34.7
Choice of contactor	34.8
Applications	34.10

## GAS/LIQUID AND LIQUID/LIQUID REACTIONS

<b>41. Kinetics of G/L and L/L reactions</b>	
The rate equation	41.1
Mass transfer without and with reaction	
How to use the general rate equation	41.9
37 problems	after 41.10
<b>42. Design of G/L and L/L reactors</b>	
Factors to consider in selecting a contactor	42.2
Design for straight mass transfer	42.6
Design for not very slow reactions	42.13
42 problems	after 42.18

## REACTION OF SOLIDS

<b>51. Kinetics of G/S reactions. The SCM for constant size particles</b>	
The shrinking core model	51.1
Clues to the controlling mechanism	51.4
SCM for non spherical particles	51.5
Final comments	51.6
49 problems	after 51.6
<b>52. G/S reactors for solids of unchanging size, known gas environment, SCM</b>	
The discrete size distribution	52.1
Design of single reactors	52.1
Reactors with elutriation, sedimentation, attrition	52.5
Multistage reactors	52.14
Extensions	52.16
56 problems	after 52.18
<b>53. G/S reactors for solids of unchanging size, changing gas environment, SCM</b>	
Single reactors	53.3
Reactor-regenerator systems	53.5
32 problems	after 53.8
<b>54. Shrinking and growing particles</b>	
Kinetics of growth and shrinkage	54.1
Measurement of size distribution	54.2
Single reactors	54.3
Plug flow, mixed flow, growth, shrinkage, single size, spread of sizes, elutriation, spherical and non spherical particles	
General procedure for shrinking particles	54.18
General procedure for growing particles	54.19
Circulation system with growth and shrinkage	54.19
Mechanism of particle growth	54.22
Mechanism of particle shrinkage	54.24
25 problems	after 54.26



<b>55. Kinetic models for the reaction of solids</b>	
SCM — the shrinking core model	55.2
UCM — the uniform conversion model	55.3
GPM — the grainy pellet model	55.4
CCM — the crackling core model	55.6
CVM — changing voidage models	55.8
TDM — thermal decomposition models	55.13
PCM — phase change models	55.16
SCM for multistep reactions	55.20
Multistep reactions of porous pellets	55.21
Multistep reactions of pellets which become porous	55.22
Comments	55.23
An unusual mechanism involving loose atoms	55.24
On the use of reaction order	55.24
22 problems	after 55.25

## FLOW OF MATERIALS THROUGH REACTORS

<b>61. Flow pattern and contacting</b>	
Overall picture of non ideal flow	61.1
RTD, state of aggregation, earliness of mixing, and their effect on reactor performance	
Conversion for a single phase, single feed reactor	61.6
Experimental methods for finding the RTD	61.8
Pulse experiment, step experiment, relationship between tracer curves	
Chemical methods for finding the RTD	61.17
Summary	61.18
61 problems	after 61.18
<b>62. Compartment models</b>	
Physical tracer methods	62.1
Chemical tracer method	62.7
49 problems	after 62.7
<b>63. The mean and variance of an RTD</b>	
$\bar{t}$ and $\sigma^2$ from pulse response data	63.1
$\bar{t}$ and $\sigma^2$ of RTD's from step response data	63.6
<b>64. The dispersion model</b>	
The physical picture	64.2
Small deviations from plug flow	64.3
Large deviations from plug flow	64.5
Step input of tracer	64.11
Correlations for axial dispersion	64.15
Chemical conversion	64.19
37 problems	after 64.21

<b>66. The tanks in series model</b>	
Pulse response experiments and the RTD	66.1
Step response experiments and the F curve	66.6
Chemical conversion	66.7
13 problems	after 66.9
<b>68. Convection model</b>	
Which model to use—convection, conversion, diffusion, etc.	68.1
Pulse response experiments and the E curve	68.3
Step response experiments and the F curve	68.6
Tracer curves for non newtonians and for non circular channels	68.8
Tracer curves for line measurements	68.12
Chemical conversion	68.13
6 problems	after 68.15

## ENZYME AND MICROBIAL REACTIONS

<b>81. Enzyme fermentation</b>	
Michaelis-Menten kinetics	81.2
Batch fermenter, mixed flow fermenter, direct fit of the M-M equation, the Eadie, Lineweaver and no name plots	
Inhibition by a foreign substance	81.9
Competitive and non competitive inhibition and how to distinguish between them	
Substrate inhibition	81.14
20 problems	after 81.15
<b>82. Microbial fermentation. Overall picture.</b>	
Constant environment fermentation	82.2
Batch fermentor	82.2
Mixed flow fermentor	82.4
Product distribution and fractional yield	82.4
Kinetic expressions, the Monod equation and its generalization	82.5
Planned treatment of subject	82.7
<b>83. Substrate limiting microbial fermentation</b>	
Batch fermentor	83.2
Mixed flow fermentor	83.5
Optimum operations	83.9
Concentration and recycle of cells	83.12
Comments	83.14
38 problems	after 83.15
<b>84. Product poison limiting microbial fermentation</b>	
Rate equation	84.1
Batch fermentor	84.2
Mixed flow fermentor	84.5
Fermentation with $n \neq 1$ poison limiting kinetics	84.7
Substrate + poison influenced kinetics	84.10
30 problems	after 84.12

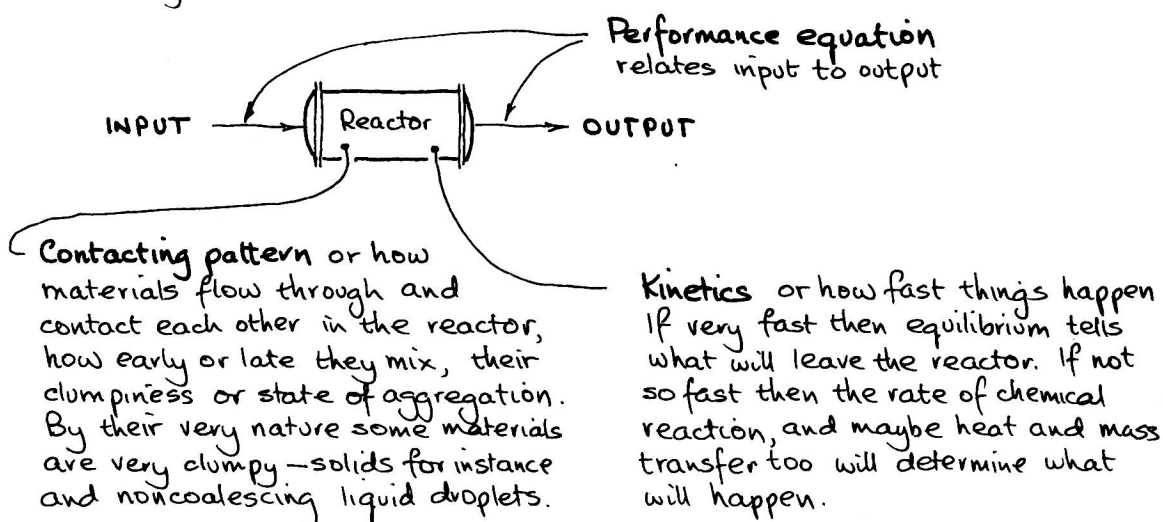
## MISCELLANY

<b>100. Dimensions, units, conversions, order of magnitude and this and that</b>	
Newton's law	100.1
Length	
Volume	
Mass	
Pressure	
Work, energy, and heat	100.2
Molecular weight	
Ideal gas	
Viscosity	
Density	100.3
Diffusivity	
Concentration	
Thermal conductivity	100.4
Heat transfer coefficient	
Mass transfer coefficient	
Rate of reaction	100.5
Dimensionless groups	

## Chapter 1 INTRODUCTION TO SINGLE PHASE CHEMICAL REACTORS.

Reactors come in all colors shapes and sizes, and are used for all sorts of reactions. As a brief sampling we have the giant cat crackers for oil refining, the monster blast furnaces for iron making, the crafty activated sludge ponds for sewage treatment, the amazing polymerization tanks for plastics, paints and fibers, the so important pharmaceutical vats for aspirin, penicillin and birth control drugs, the happy go lucky fermentation jugs for moonshine, and of course that abomination, the beastly cigarette.

To find what a reactor is able to do we need to know the kinetics, the contacting pattern and the performance equation. Schematically



Much of this book deals with finding the expression to relate input to output for various kinetics and various contacting patterns, or

$$\text{output} = f[\text{input, kinetics, contacting}]$$

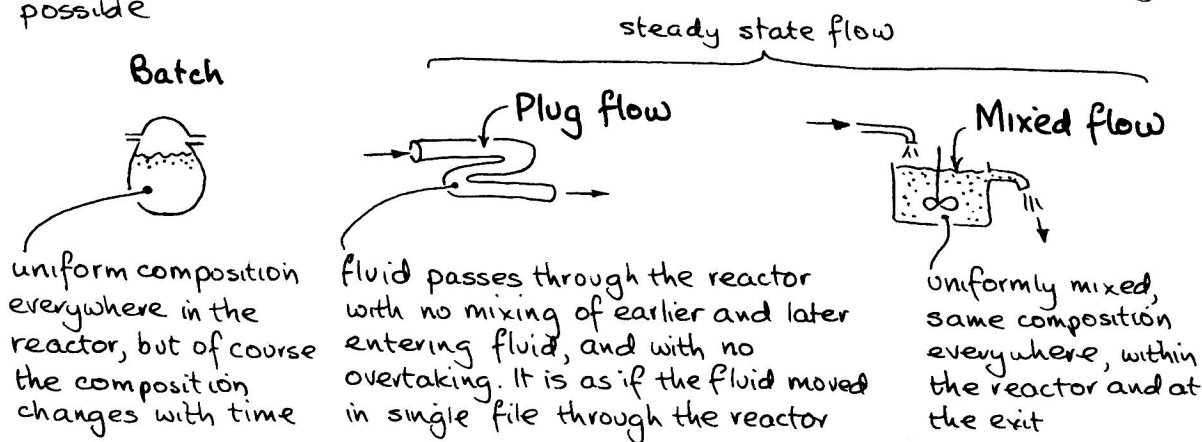
This is called the **performance equation**. Why is this important? Because with this expression we can compare different designs and conditions, find which is best, and then scale up to larger units.



We first consider single phase systems. Think of these as a single gas or liquid flowing through the reactor and reacting therein. We treat these systems rather thoroughly (chapters 1~9) since the principles learned there carry over in large part to the much more difficult and important problem of design of heterogeneous reacting systems, those where two or more phases contact each other and react.

### A. Some simple reactor types.


We start with the idealized flow patterns shown below and we very often try to make real reactors approach these ideals as closely as possible



We particularly like these three flow or reacting patterns because they are easy to treat (it is simple to find their performance equations) and because one of them often is the best pattern possible (it will give the most of whatever it is we want). Later we will consider

recycle reactors 

and

staged reactors 

and other flow pattern combinations, including deviations of real reactors from these ideals.