

# CONTENTS

## VOLUME I.

PREFACE .....	11
LIST OF BASIC SYMBOLS .....	12
<b>1 INTRODUCTION .....</b>	<b>17</b>
1.1 ADVANTAGES OF RADIOISOTOPE METHODS .....	17
1.2 CLASSIFICATION AND PRINCIPLES OF RADIOISOTOPE METHODS .....	17
1.3 DEFINITION OF FREQUENTLY USED TERMS .....	21
1.4 ORGANIZATION OF THE BOOK AND PERSPECTIVE OF RADIOISOTOPE METHODS .....	23
1.5 REFERENCES [1-x] .....	24
<b>2 THE STIMULUS RESPONSE TECHNIQUE. ....</b>	<b>25</b>
<b>2.1 RESIDENCE TIME AND AGE OF PARTICLES-CHARACTERISTICS ...</b>	<b>25</b>
<b>2.2 DEPENDENCE OF RESPONSE TO A STIMULUS FUNCTION .....</b>	<b>30</b>
<b>2.3 INTEGRAL TRANSFORMATIONS (TRANSFER, FREQUENCY         CHARACTERISTICS AND CORRELATIONS) .....</b>	<b>33</b>
2.3.1 Transfer function, Laplace's transformation .....	33
2.3.2 Frequency response, Fourier transformation .....	34
2.3.3 Correlations .....	36
2.3.4 FFT .....	40
<b>2.4 NUMERICAL CHARACTERISTICS .....</b>	<b>42</b>
<b>2.5 EXPERIMENTAL DETERMINATION OF RESPONSE         CHARACTERISTICS .....</b>	<b>46</b>
2.5.1 Determination of response characteristics from the response to an impuls ....	48
2.5.2 Determination of response characteristics from a response to a general pulse	63
2.5.3 Determination of $f(t)$ from impulse response distorted with another system ...	71
2.5.4 Determination of $f(t)$ from impulse response which is distorted by recycle ....	72
2.5.5 Determination of response characteristics from the response to a random signal	74
2.5.6 The response of a system with several input and output material streams .....	78
<b>2.6 MODELS OF PROCESS RESPONSES .....</b>	<b>82</b>
2.6.1 Mathematical approximation models .....	82
2.6.2 Basic models with lumped parameters (ideal mixing and displacement) ....	83
2.6.3 Dispersion models .....	90

2.6.4	Combined models	96
2.6.4.1	Combined model of nonideal mixing	97
2.6.4.2	Combined model with ineffective regions	99
2.6.4.3	System of subsystem in series	102
2.6.4.4	System of parallel subsystems	105
2.6.4.5	System with recirculation	106
2.6.4.6	Complex systems. Gradual simplification. Numerical methods.	114
2.6.5	Convective models	115
2.6.6	Computer Fluid Dynamics models	116
2.6.7	Models of detection system	121
<b>2.7</b>	<b>SELECTION AND IDENTIFICATION OF MODELS</b>	<b>126</b>
2.7.1	Selection of models by using single or multiple detectors	126
2.7.2	Parameter identification	129
2.7.2.1	Linearisation method for distribution functions	129
2.7.2.2	Linearisation method for transfer function	130
2.7.2.3	Estimate of parameters based on matching characteristic points	132
2.7.2.4	Optimisation methods (nonlinear regression)	133
<b>2.8</b>	<b>UTILIZATION OF RESPONSE CHARACTERISTICS IN STUDY AND MODELLING OF PROCESSES</b>	<b>135</b>
2.8.1	Axial dispersion and holdup evaluation. Packed column testing.	139
2.8.2	Contribution of RTD analysis to Mass Transfer Process. Continuous steel production	141
2.8.3	Mean Residence time and RTD in horizontal rotary drum.	143
2.8.4	Impulse response analysis in pseudocontinuous process. Evaluation of flow characteristics and discharging sequence of particulate solids from silos.	147
2.8.5	Analysis of process kinetics. Process of crushing and screening in a hammer mill	151
2.8.6	Process control at transient state. Analysis of gas flow in the Pressurized Fluidized Bed Combustor- PFBC.	155
2.8.7	Identification, system with recirculation, modelling. Biological activation process. Waste water treatment.	158
2.8.8	RTD prediction for different Re by CFD. Gas flow analysis in electron beam chamber.	163
<b>2.9</b>	<b>COMPLEX PROCESS ANALYSIS.</b>	<b>170</b>
2.9.1	Separation.	171
2.9.2	Grinding.	178
2.9.3	Granulation.	181
2.9.4	Reactions	183
2.9.4.1	Chemical reactions	183
2.9.4.2	Bioreactions	198
2.9.5	Analysis of an recirculation effect of the chemical reaction in melting process.	199
2.9.6	Gradual simplification of complex systems	201



2.9.6.1	Fertilizer production. . . . .	203
2.9.6.2	Dye production - white filtration of titanium dioxide. . . . .	206

**2.10 RESPONSE CHARACTERISTICS FOR CONTROL SYSTEMS. PROCESS CONTROL IN STATIONARY CONDITIONS. . . . . 210**

2.10.1	Models of transfer function. . . . .	211
2.10.1.1	First order systems with time delay. . . . .	212
2.10.1.2	Higher order systems with time delay. . . . .	212
2.10.1.3	Second order systems with two different constants and with time delay. . . . .	213
2.10.1.4	$n$ th order systems with one $n$ -fold constant and with time delay. . . . .	214
2.10.2	Approximation of complicated transfer function. . . . .	216
2.10.3	Examples of radiotracer applications in modelling of control systems. . . . .	217
2.10.3.1	Frequency characteristic - gain factor = amplitude ratio. Glass industry. . . . .	218
2.10.3.2	Transfer function of reactors in series. Wet part of NPK fertilizer production. . . . .	219
2.10.3.3	The frequency characteristics of apparatuses in series. Multistep bleaching process of sulfate pulp. . . . .	222
2.10.4	Process control at unsteady conditions. . . . .	224
2.10.4.1	The control of process intensification. Production of aldehydes. . . . .	224

**2.11 APPLICATION OF RESPONSE CHARACTERISTICS FOR EQUALIZATION. . . . . 228**

2.11.1	Application of distribution functions. . . . .	229
2.11.2	Application of frequency characteristics. . . . .	231
2.11.3	Application of approximation models. . . . .	233
2.11.4	Application of radiotracers in valuation of equalization. . . . .	238
2.11.4.1	Influence of dead volume on equalization effect. Equalization efficiency of a continuous gravity blender. . . . .	238
2.11.4.2	Influence of radial and axial mixing of liquid on the equalization effect. Equalization of quantities of liquid in a mixed vessel. . . . .	241
2.11.4.3	Influence of inlet flow in the circular basin on equalization. Equalization of variation of impurities in waste water treatment . . . . .	243
2.11.4.4	Influence of recirculation on equalization effect. . . . .	244
2.11.5	Optimization of an equalization process. Application of disturbance attenuation capability. . . . .	245

**2.12 THE EVALUATION OF CONTINUOUS PROCESS FROM RESULTS OF THE BATCH PROCESS OR FROM PROCESS KINETICS. . . . . 251**

2.12.1	RTD of liquid and solid particles in two phases system in multistage column reactor. . . . .	252
2.12.2	Superposition of kinetics dependence and distribution function . . . . .	257
2.12.2.1	Drying in fluidized bed . . . . .	257
2.12.2.2	Distribution of particle dimension in a continuous crystallizing tank . . . . .	259
2.12.2.3	Irradiation or thermal treatment of material in continuous system . . . . .	260



<b>2.13</b>	<b>RESPONSE CHARACTERISTICS IN UNSTEADY STATE . . . . .</b>	<b>271</b>
2.13.1	Effective volume in variable flow . . . . .	273
2.13.2	Distribution functions of residence time in variable flow . . . . .	275
2.13.3	Distribution functions of residence time in variable flow and volume . . . . .	276
<b>2.14</b>	<b>SOFTWARE AND ITS APPLICATION . . . . .</b>	<b>279</b>
2.14.1	Software for impulse response analysis . . . . .	280
2.14.1.1	RTD Software Analysis . . . . .	280
2.14.1.2	DTS PRO Software for interpretation of tracer experiments in industrial processes . . . . .	286
2.14.2	Verification of CFD methods by stimulus response methods . . . . .	289
2.14.2.1	Algorithms for detector systems . . . . .	290
2.14.2.2	Processing of CFD data . . . . .	291
2.14.2.3	Example of CFD verification by RTD experiment . . . . .	293
<b>2.15</b>	<b>RADIOTRACER METHODS PLANNING AND SAFETY REGULATIONS (T.Čechák, J.Klusoň) . . . . .</b>	<b>297</b>
2.15.1	Method of tracer transport monitoring . . . . .	298
2.15.1.1	Sampling methods . . . . .	298
2.15.1.2	Continual measurement of response . . . . .	298
2.15.2	Tracer selection . . . . .	298
2.15.2.1	Physically-chemical form and properties . . . . .	298
2.15.2.2	Radionuclides photon energies and half-life . . . . .	299
2.15.2.3	Specific activity . . . . .	299
2.15.2.4	Injection technique . . . . .	300
2.15.2.5	Activity estimation . . . . .	301
2.15.3	Detection system design . . . . .	305
2.15.3.1	Detectors . . . . .	305
2.15.3.2	Detector collimation . . . . .	307
2.15.3.3	Detector shielding . . . . .	308
2.15.3.4	Signal processing . . . . .	308
2.15.3.5	Time of measurement . . . . .	309
2.15.3.6	Calibration factor . . . . .	309
2.15.4	Safety regulations . . . . .	314
2.15.4.1	Planning of an experiment . . . . .	314
2.15.4.2	Taking the radionuclide sources . . . . .	315
2.15.4.3	Transport of radioactive sources . . . . .	315
2.15.4.4	Delineation of the controlled areas . . . . .	315
2.15.4.5	Basic limits of effective doses . . . . .	316
2.15.4.6	Requirements for handling with radioactive wastes . . . . .	317
<b>2.16</b>	<b>REFERENCES [2-X]. . . . .</b>	<b>318</b>