ROBIN SMITH

CHEMICAL PROCESS DESIGN

化工过程设计

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To Christine, Rachele,
Nicholas, and Anna

Preface

Chemical process design starts with the selection of a series of processing steps and their interconnection into a flowsheet to transform raw materials into desired products. Whereas a great emphasis in chemical engineering traditionally has been placed on the analysis or simulation of flowsheets, the creation or synthesis of flowsheets has received, by comparison, little attention. Yet the decisions made during the synthesis of the flowsheet are of paramount importance in determining the economic viability, safety, and environmental impact of the final design. This text will concentrate on developing an understanding of the concepts required at each stage of the synthesis of process flowsheets.

Chemical processes will in the future need to be designed as part of a sustainable industrial development which retains the capacity of ecosystems to support industrial activity and life. This book therefore places a high emphasis on waste minimization and energy efficiency in the context of good economic performance and good health and safety practices.

The structure of the text largely follows the order in which the decisions should be made during the development of a process design. Economic evaluation has been included, but as an appendix so as not to interrupt the flow of the text. This book is intended to provide a practical guide to chemical process design for advanced undergraduate and postgraduate students of chemical engineering, practicing process designers, and practicing chemical engineers working in process development.

Robin Smith

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Nomenclature

a	order of reaction (–) or cost law coefficient (–)
A	heat exchanger area (m^2) or annual cash flow ($)
$A_{NETWORK}$	heat exchanger network area target (m^2)
b	order of reaction (–) or cost law coefficient (–)
BOD	biological oxygen demand (mg $liter^{-1}$)
c	cost law coefficient (–)
C	number of components in heat exchanger network design (–)
C_{FEED}	molar concentration of FEED (kmol m^{-3})
C_P	specific heat capacity (kJ kg^{-1} K^{-1})
$C_{PRODUCT}$	molar concentration of PRODUCT (kmol m^{-3})
COD	chemical oxygen demand (mg $liter^{-1}$)
COP_{HP}	coefficients of performance of heat pump (–)
COP_{REF}	coefficients of performance of refrigeration system (–)
CP	heat capacity flowrate (kJ s^{-1} K^{-1})
$CP_{EXHAUST}$	heat capacity flowrate of heat engine exhaust (kJ kg^{-1} K^{-1})
CW	cooling water
D	distillate flow rate (kg s^{-1}, kmol s^{-1})
EP	economic potential ($ yr^{-1})
f	cost factor to allow for design pressure, material of construction, or installation costs (–)
F	feed flow rate (kg s^{-1}, kmol s^{-1}) or future worth of a sum of money allowing for interest rates ($)
F_T	correction factor for noncountercurrent flow in shell and tube heat exchangers (–)

F_{Tmin}	minimum acceptable F_T for noncountercurrent heat exchangers
h_i	specific enthalpy ($kJ\,kg^{-1}$) or film heat transfer coefficient ($kJ\,m^{-2}\,s^{-1}\,K^{-1}$)
H	stream enthalpy ($kJ\,s^{-1}$)
HP	high pressure
i	component or stream number (–) or fractional rate of interest on money (–)
I	total number of hot streams (–) or capital cost investment ($)
j	stream number (–)
J	total number of cold streams (–)
K	total number of enthalpy intervals in heat exchanger networks (–)
K_i	ratio of vapor to liquid composition at equilibrium for component i (–)
k	reaction-rate constant (units depend on order of reaction) or enthalpy interval number in heat exchanger networks (–)
L	liquid flow rate ($kg\,s^{-1}$, $kmol\,s^{-1}$) or number of independent loops in a network (–)
LP	low pressure (–)
m	mass, molar flow rate ($kg\,s^{-1}$, $kmol\,s^{-1}$)
MP	medium pressure (–)
N	number of 1–2 shell-and-tube heat exchangers per match (–)
N_{SHELLS}	number of 1–2 shell-and-tube heat exchangers (–)
N_{UNIT}	number of units (–)
NC	number of components in a multicomponent mixture (–)
NPV	net present value ($)
P	pressure ($N\,m^{-2}$) or thermal effectiveness of 1–2 shell-and-tube heat exchanger (–) or present worth of a future sum of money ($)
P_{max}	maximum thermal effectiveness of 1-2 shell-and-tube heat exchangers (–)
P_{N-2N}	thermal effectiveness over N number of 1–2 shell-and-tube heat exchangers in series (–)
P_{1-2}	thermal effectiveness over each 1–2 shell-and-tube heat exchanger in series (–)
q	thermal condition of the feed in distillation (–)
q_i	individual stream heat duty ($kJ\,s^{-1}$)

Q	heat duty ($kJ\,s^{-1}$)
Q_C	cooling duty ($kJ\,s^{-1}$)
$Q_{C\min}$	target for cold utility ($kJ\,s^{-1}$)
Q_{COND}	condenser heat duty ($kJ\,s^{-1}$)
Q_{EXHAUST}	heat duty for heat engine exhaust ($kJ\,s^{-1}$)
Q_{FUEL}	heat from fuel in a furnace, boiler, or gas turbine ($kJ\,s^{-1}$)
$Q_{H\min}$	target for hot utility ($kJ\,s^{-1}$)
Q_{HE}	heat engine duty ($kJ\,s^{-1}$)
Q_{HP}	heat pump duty ($kJ\,s^{-1}$)
Q_{LOSS}	stack loss from furnace, boiler, or gas turbine ($kJ\,s^{-1}$)
Q_{REACT}	reactor heating or cooling duty ($kJ\,s^{-1}$)
Q_{REB}	reboiler heat duty ($kJ\,s^{-1}$)
Q_{REC}	target for heat recovery ($kJ\,s^{-1}$)
r	rate of reaction ($kmol\,m^{-3}\,s^{-1}$)
R	distillation column reflux ratio (–) or heat capacity ratio of 1–2 shell-and-tube heat exchanger (–)
$R_{\min}$	minimum reflux ratio (–)
s	specific entropy ($kJ\,kg^{-1}\,K^{-1}$)
S	reactor selectivity (–) or number of streams in heat exchanger network (–)
S_C	number of cold streams (–)
S_H	number of hot streams (–)
T_{BT}	normal boiling point (°C, K)
T	temperature (°C, K)
T_C	cold-stream temperature (°C, K)
T_{COND}	condenser temperature (°C, K)
T_H	hot-stream temperature (°C, K)
T_{REB}	reboiler temperature (°C, K)
T_S	stream supply temperature (°C, K)
T_T	stream target temperature (°C, K)
T^*	interval temperature; hot streams are represented $\Delta T_{\min}/2$ colder and cold streams $\Delta T_{\min}/2$ hotter than actual temperature (°C, K)
ΔT_{LM}	logarithmic mean temperature difference (°C, K)
$\Delta T_{\min}$	minimum temperature difference (°C, K)
$\Delta T_{\mathrm{THRESHOLD}}$	threshold temperature difference (°C, K)
TOD	total oxygen demand ($mg\,liter^{-1}$)
U	overall heat transfer coefficient ($kJ\,m^{-2}\,s^{-1}\,K^{-1}$)
V	vapor flow ($kg\,s^{-1}$, $kmol\,s^{-1}$)
$V_{\min}$	minimum vapor flow ($kg\,s^{-1}$, $kmol\,s^{-1}$)

VF	vapor fraction (–)
W	shaftwork (kJ s^{-1})
x	liquid-phase mole fraction (–) or steam wetness fraction (–)
x_F	mole fraction in the feed (–)
x_D	mole fraction in the distillate (–)
X	reactor conversion (–)
X_E	equilibrium reactor conversion (–)
X_{OPT}	optimal reactor conversion (–)
X_P	fraction of maximum thermal effectiveness P_{max} allowed in a 1–2 shell-and-tube heat exchanger (–)
XP	cross-pinch heat transfer in heat exchanger network (kJ s^{-1})
y	vapor-phase mole fraction (–)
z	feed mole fraction (–)

Greek Letters

α	relative volatility (–)
λ	latent heat of vaporization (kJ kg^{-1})
η	Carnot factor (–) or efficiency (–)
η_T	turbine isentropic efficiency (–)
θ	parameter in the Underwood equation
ϕ	cost weighing factor applied to film heat transfer coefficients to allow for mixed materials of construction, pressure rating, and equipment types in heat exchanger networks

ABOUT THE AUTHOR

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