Cairo University

REGENERATION DYNAMICS OF STEAMED OUT ADSORPTIVE BEDS

By

Nourhan Hisham Mohamed Rabea Khashaba

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Chemical Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Thesis Title:

REGENERATION DYNAMICS OF STEAMED OUT ADSORPTIVE BEDS

Key Words:
Particle drying; fixed beds; fluidized beds; modeling.

Summary:

The present work addresses modeling of the dynamics of heat and mass transfer in the regeneration of adsorptive particle beds focusing on the drying and cooling phase where hot air is first admitted for moisture removal and cold air is introduced to bring about the required bed cooling. Three schemes are studied for the air temperature policy adopted in this drying-cooling phase.

The first part of the work presents the development of a lumped parameter dynamic model to describe the evolution of temperature and moisture content within fluidized beds. This is followed by mimicking the behavior of a fixed bed by partitioning the bed into small lumped parameter increments to model its distributed parameter behavior.

The third part addresses the effect of intra-particle mass diffusion resistance. The results cover models for constant rate drying and their comparison with the falling rate behavior when the intra-particle mass transfer resistance is considered.

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Dedication

This thesis is dedicated to my family.

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Nomenclature

c	Heat capacity	cal gm^{-1} K^{-1}
G	Dry air mass flow rate	gm sec^{-1}
D	Knudsen diffusion coefficient	cm^{2} sec^{-1}
hg	Heat transfer coefficient in the gas phase	cal sec^{-1} cm^{-2} K^{-1}
H	Air enthalpy	cal gm dry air^{-1}
Hg	Dry gas hold up in the bed	gm
K	Thermal conductivity	cal sec^{-1} cm^{-1} K^{-1}
Kg	Mass transfer coefficient in the gas phase	gm sec^{-1} cm^{-2} mmHg^{-1}
M_v	Molecular weight of water vapor	gm gmole^{-1}
p	Partial pressure of water vapor	mmHg
r	Particle radius coordinate	cm
R_p	Particle radius	cm
S	Weight of solids in the bed	gm
T	Particle temperature	°C
T_1	Particle temperature at interior collocation point	°C
t	Time	sec
$\bar{t}$	Switching time	min
W	Air humidity ratio	gm water/ gm dry air
X	Particle moisture content on dry basis	gm water/ gm dry solid

Greek letters:

α	Specific area of charcoal	cm^{2} gm^{-1}
ε	Bed porosity	
λ	Latent heat of vaporization	cal gm^{-1}
θ	Air temperature	°C
ρ	Density	gm cm^{-3}
σ	Dried increment of the particle	cm
τ	Heater time constant	min
τ_p	Tortuosity factor, has a value of 4	
ω	Dimensionless radius, r/R	

Subscripts:

a	ambient
f	feed
g	gas
i	interface

o	outlet
p	particle
r	reference
sd	dry solid
sw	wet solid
t	transient
u	ultimate
w	water

Abstract

Drying is an important process in many fields such as chemical, agricultural, ceramics and pharmaceutical industries. It may be done to have free-flowing solids that are easy to handle, to facilitate the preservation and storage of different materials, to reduce the transportation costs or to achieve desired quality of products.

One of the industrial drying applications is the regeneration of adsorptive particle beds. The operation of such beds includes three periods. During the first period adsorption takes place till breakthrough. This is followed by steaming period where live steam is blown through the bed to remove the adsorbate from the solid adsorbent. In the third period; regeneration period, the hot, moist bed is dried and cooled to be ready for the next adsorption cycle.

The present work addresses modeling of the dynamics of heat and mass transfer in the regeneration of adsorptive particle beds focusing on the drying and cooling phase where hot air is first admitted for moisture removal and cold air is introduced to bring about the required bed cooling. Three schemes will be studied for the air temperature policy adopted in this drying-cooling phase. These include idealized (square) and more realistic (saw-tooth like) heat pulses.

The first part of the work presents the development of a lumped parameter dynamic model to describe the evolution of temperature and moisture content within fluidized beds, taking into consideration the conservation of mass and heat within the bed as well as the variation of the system physico-chemical parameters with changes of temperature and moisture content. This is followed by mimicking the behavior of a fixed bed by partitioning the bed into small lumped parameter increments to model its distributed parameter behavior.

The third part addresses the effect of intra-particle mass diffusion resistance by considering the difference in behavior on neglecting intra-particle diffusion and when a suitable value of the Knudsen diffusion coefficient is assigned to the particle moisture content.

The results cover models for constant rate drying and their comparison with the falling rate behavior when the intra-particle mass transfer resistance is considered.

Chapter 1 : Introduction

Drying is a simultaneous mass and heat transfer process that converts a liquid, solid or semi-solid feedstock into a solid product having lower moisture content. This is usually done by applying heat to evaporate the liquid into a vapor phase [1].

As drying must involve a phase change of the liquid to be removed, it is considered as one of the most energy-intensive unit operations. This is due to the high latent heat of vaporization, as well as, the inefficiency of using hot air as the most common drying medium. Hence, the operating cost of dryers represents their major cost item [2].

Regeneration of adsorptive beds is an important drying application. The operation of such beds includes three periods. During the first period adsorption takes place till breakthrough. This is followed by steaming period where live steam is blown through the bed to remove the adsorbate from the solid desiccant. In the third period; regeneration period, the hot, moist bed is dried and cooled to be ready for the next adsorption cycle.

This study concentrates on the regeneration period, where hot air is first admitted for moisture removal. Then cold air is supplied for bed cooling.

Chapter 2 provides a detailed literature review of the previous studies dealing with modeling of heat and mass transfer in drying processes.

Chapter 3 summarizes the points that will be covered by the proposed dynamic models.

Chapter 4 details the development of the models used to simulate the regeneration of hot moist adsorption beds outlining the major assumptions that have been applied. This is followed by outlining the solution algorithm adopted for the simulation of alternative boundary conditions.

Chapter 5 presents the results of dynamic behavior both for fluidized beds and for fixed beds of adsorbent and the comparison of the obtained results when constant drying rate is assumed and when falling rate behavior is taken into account by considering the intra-particle mass transfer resistance.

Chapter 6 summarizes the conclusion of this work along with recommendations for future work.