

**THE EFFECTS OF AIR SPARGING
ON
ULTRAFILTRATION OF WHEY**

TAN CHING SOON

**SUBMISSION OF DISSERTATION FOR
THE FULFILLMENT OF
THE MASTER OF TECHNOLOGY
(ENVIRONMENTAL MANAGEMENT)**

**INSTITUTE OF POSTGRADUATE STUDIES
UNIVERSITY OF MALAYA
KUALA LUMPUR
JUNE 2002**

Perpustakaan Universiti Malaya



A511766842

Abstract

This work concerns the use of gas-liquid two-phase flow to reduce whey proteins and particle membrane fouling in hollow fibre dialyzer by injecting air directly into the whey feed stream. The effects of air bubbles on the permeate flux of the air sparged ultrafiltration system were studied experimentally. In comparison to single phase flow, over the range of operating conditions studied, the gas-liquid two-phase flow increases the ultrafiltration flux by 15% to 87%. The highest gas injection ratio $F_{\text{gas}}/(F_{\text{liq}}+F_{\text{gas}})$ was found to be in the range of 0.4 to 0.5. Within this range, the bulk concentration of whey proteins increases to approximately 210% after 3 hours, in comparison to a value of less than 100% for the single phase operation. Dimensionless numbers were introduced and a correlation was suggested to model the flux enhancement.

Acknowledgements

Firstly, I would like to express my deepest appreciation to my principal supervisor, Professor Mohd. Ali Hashim and my co-supervisor, Dr. Bhaskar Sen Gupta, for their assistance, invaluable guidance and commitment rendered throughout the duration of this work. I am also indebted to Professor Zhanfeng Cui and Dr. Raja Ghosh, both from the University of Oxford, for their helpful comments and suggestions.

My heartfelt thanks to Dr. Sekaran Muniandy and Mrs Kalaiselvi Palani for their assistance in some of my experimental work. My sincere thanks also go to my friends and family members for their kind assistance and moral support over the duration of the project.

Finally, I am indebted to the University of Malaya for the award of a postgraduate fellowship and for financing the research work.

Contents

Abstracts	ii
Acknowledgements	iii
Contents	iv
List of Figures	vii
List of Tables	viii
List of Symbols and Abbreviations	ix
CHAPTER ONE: INTRODUCTION	1
CHAPTER TWO: LITERATURE REVIEW	
2.1 Introduction to Membrane Processes	7
2.2 Membrane Processes in Dairy Products	8
2.3 Ultrafiltration in Dairy Products and Waste Treatment	11
2.3.1 General Applications of Ultrafiltrations	11
2.3.2 Ultrafiltration in Cheese Production	12
2.3.2.1 Principal of Cheese Curd Making	12
2.3.2.2 Milk as a Raw Material for Cheese	13
2.3.2.3 Proteins in Milk	15
2.3.2.4 Cheese Whey Ultrafiltration	16
2.3.2.5 Whey Treatment	18
2.3.3 Protein Concentration and Separation	19
2.4 Limitation of Membrane Processes	20
2.5 Gas Sparging in Ultrafiltration	22
2.5.1 Reduction of Fouling	22
2.5.2 Enhancement of Gas Sparging on Filtration	23

2.6	Mathematical Models	27
2.6.1	Pore Flow Model	28
2.6.2	Concentration Polarization Model	29
2.6.3	Mass Transfer (Film Theory) Coefficient	31
2.6.4	Development of Dimensionless Numbers at Pressure Dependent Region	35
2.6.5	Resistance Model and Osmotic Pressure Model	37
2.6.6	Dimensionless Numbers	39
2.7	Protein Analysis	39
2.7.1	Analytical Gel Electrophoresis	40
2.7.2	Determination of the Total Protein	41

CHAPTER THREE: MATERIALS AND METHODS

3.1	Membrane Selection	44
3.2	Milk Solution Preparation	44
3.3	Experimental Set-up	45
3.4	Experimental Procedure	47
3.4.1	Total Recycle Operation	47
3.4.2	Batch Concentration	49
3.5	Enhancement Analysis	49
3.6	Protein Analysis	50
3.6.1	Total Protein Measurement (Bradford Protein Assay)	50
3.6.2	Sodium Dodecyl Suphate Polyacrilamide Gel Electrophoresis (SDS-PAGE)	51

CHAPTER FOUR: RESULTS AND DISCUSSION	
4.1 Permeate Flux in Total Recycle Operation	55
4.2 Dimensionless Numbers	60
4.3 Membrane Rejection	64
4.4 Batch Concentration Operation	66
 CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS	 70
Appendix 1 Experimental Data	71
Appendix 2.1 Determination of Membrane Resistance	77
Appendix 2.2 Formula for Flux Calculations	79
References	80

List of Figures

Figure 2.1	Sequential membrane processing in the dairy industry	9
Figure 2.2	Size distribution of components in milk (right) and whey (left), showing possible application of membrane technology	10
Figure 2.3	Flowchart of raw cheese production from milk	13
Figure 2.4	Some methods for the disposal of whey	17
Figure 2.5	Experimental setup for gas sparging	24
Figure 2.6	Concentration profile during membrane processing of partially or completely rejected solutes	27
Figure 2.7	Schematic representation of the cross section of typical asymmetric ultrafiltration membrane or microfiltration membrane	29
Figure 2.8	The effect of pressure, stirring rate and albumin protein concentration on flux	31
Figure 2.9	Concentration polarization of membrane	31
Figure 2.10	Schematic diagram showing the buildup of the polarized gel layer and associated boundary layer	33
Figure 3.1	Experimental setup for air sparging ultrafiltration system	46
Figure 4.1	The effect of air sparging on permeate flux	56
Figure 4.2	Influence of gas flow rate on permeate flux	58
Figure 4.3	Graph flux improvement compare with single phase operation	62
Figure 4.4	Comparison between experimental and predicted flux number	63
Figure 4.5	Enhancement of gas sparging in batch concentration operation	68
Figure 4.6	Effect of gas sparging in batch concentration operation	69

List of Tables

Table 2.1	Composition of cow's milk as a raw material for cheese	14
Table 2.2	Whey concentration using ultrafiltration	19
Table 2.3	Approaches to minimize flux degradation	23
Table 3.1	Characteristics of membrane 28H IDEMSA	44
Table 3.2	Content of full cream milk	45
Table 3.3	Stock solution needed for sodium dodecyl sulphate polyacrilamide gel electrophoresis	52
Table 3.4	Preparation of gels for sodium dodecyl sulphate polyacrilamide gel electrophoresis	53
Table 4.1	Flux improvement at different operation conditions	57
Table 4.2	Transmission of whey protein in ultrafiltration at transmembrane pressure=0.45bar (total recycle)	64
Table 4.3	Transmission of whey proteins in ultrafiltration for batch concentration operation	65
Table A1.1	Flux obtained from total recycle operation	71
Table A1.2	Enhancement of flux comparison to single phase flow	72
Table A1.3	Average flux in different conditions	73
Table A1.4	Flux improvement (%) compare to single phase flow	73
Table A1.5	Data for dimensionless plotting	74
Table A1.6	Data for batch concentration process	75
Table A1.7	Protein concentration and transmission (batch concentration process)	76

Symbols and Abbreviations

A	membrane area (m^2)
ABS	UV adsorption
BOD	biological oxygen demand (mg/L)
BSA	Bovine Serum Albumin
C	solute concentration (mg/L)
C_f	feed concentration (mg/L)
C_b	bulk concentration (mg/L)
C_w	concentration at membrane surface/wall (mg/L)
C_p	solute concentration of permeate (mg/L)
C_s	saturation concentration (mg/L)
C_g	gelation concentration (mg/L)
d_p	channel diameter (μm)
D	diffusivity of macromolecules (m^2s^{-1})
Da	Dalton
E	electrical field (V)
Eqn.	equation
F	force (kgms^{-2})
F_{liq}	liquid flowrate (L/min)
F_{gas}	gas flowrate (L/min)
IgG	immunoglobulin G
J ,	permeate flux (m/s or $\text{mL/m}^2\text{s}$)
J_{obtained}	permeate flux obtained in operation (m/s or $\text{mL/m}^2\text{s}$)
$J_{\text{single-phase}}$	permeate flux for single-phase operation (m/s or $\text{mL/m}^2\text{s}$)

J_w	flux of pure water (m/s or mL/m ² s)
k	mass transfer coefficient (m/s)
LPM	liter per minute (L/min)
MF	micro filtration
MW	molecular weight
MWCO	molecular weight cutoff
NF	nano filtration
OD	outer diameter (m)
PAGE	polyacrilamide gel electrophoresis
ppm	part per million
P_F	feed pressure (kg/ms ²)
P_p	permeate pressure (kg/ms ²)
P_T	applied transmembrane pressure (kg/ms ²)
R_f	hydraulic retention due to total fouling (m ⁻¹)
R_m	hydraulic retention due to membrane (m ⁻¹)
Re	Reynolds number (dimensionless)
RO	reverse osmosis
Sc	Schmidt number (dimensionless)
SDS	sodium dodecyl sulphate
Sh	Sherwood number (dimensionless)
t	time (s)
TEMED	N,N,N',N'- tetramethylethylenediamine.
TMP	transmembrane pressure (kg/ms ²)
T_{ob}	observed tranmission
UF	ultrafiltration

U_L	liquid velocity (m/s)
U_g	gas velocity (m/s)
V_p	volume of permeate (mL)
Z	net charge (C)
Π_F	difference in osmotic pressure in feed (kg/ms ²)
Π_p	difference in osmotic pressure in permeate (kg/ms ²)
μ	dynamic viscosity of liquid (kgms ⁻¹ or Ns./m ²)
ε	porosity of membrane (m ²)
Δ	delta
δ_b	concentration boundary layer (m)
γ	shear rate (s ⁻¹)