STUDY ON EFFECT OF SCALE FORMATION IN EVAPORATORS OF SUGAR INDUSTRY USING EXPERIMENTAL AND MATHEMATICAL MODELING

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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ABSTRACT

This study focuses sugar factory evaporators in Sri Lanka. Multiple effect evaporators are employed in concentrating the clarified cane juice in sugar factories in Sri Lanka. Scale formation on heat transfer surfaces in sugar factory evaporators has a highly deleterious effect on specific energy consumption and production capacity. This thesis introduces combined experimental and mathematical modeling approach to study the effect of rate of scale formation in evaporators. Prior to develop mathematical model the rate of scale formation was experimentally investigated by analyzing evaporator scale, clear juice and syrup in two sugar factories in Sri Lanka. The model was developed using MATLAB software. The built mathematical model consists of two fouling phenomenal namely, particulate fouling and chemical precipitation fouling. The model shows the development of scale in each evaporator and temperature variation in each evaporator. The model also indicates the effect of following a scale reduction technique by comparing temperature variation in each evaporator before and after using a scale reduction technique.
DEDICATION

Dedicated with gratitude

To my loving PARENTS

For being

The greatest pliers of my life.
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I believe that my research would make a small contribution to the vast ocean of scientific research conducted in the field of Sugar Technology.

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# TABLE OF CONTENTS

DECLARATION OF THE CANDIDATE AND SUPERVISOR ................................................. ii
ABSTRACT .......................................................................................................................... iii
DEDICATION ...................................................................................................................... iv
ACKNOWLEDGEMENT ....................................................................................................... v
TABLE OF CONTENTS .................................................................................................... vii
LIST OF FIGURES ........................................................................................................... x
LIST OF TABLES ............................................................................................................... xii
NOMENCLATURE .............................................................................................................. xiii
1. INTRODUCTION ........................................................................................................ 1
   1.1. Background .......................................................................................................... 1
   1.2. Introduction to research problem ...................................................................... 2
   1.3. Research objectives .......................................................................................... 2
   1.4. Research strategy ............................................................................................. 2
   1.5. Outline of the research .................................................................................... 3
   1.6. Summary of the thesis ...................................................................................... 4
2. LITERATURE REVIEW .......................................................................................... 6
   2.1 Cane sugar manufacturing in Sri Lanka ........................................................... 6
      2.1.1 Cane preparation ......................................................................................... 6
      2.1.2 Juice extraction .......................................................................................... 7
      2.1.3 Juice Clarification ....................................................................................... 7
      2.1.4 Juice Concentration in Evaporators .......................................................... 8
      2.1.5 Pan boiling of the syrup .............................................................................. 8
      2.1.6 Separation of Sugar Crystals ................................................................. 9
      2.1.7 Drying of Sugar ......................................................................................... 9
   2.2 Function of the multiple effect evaporators in sugar factories ....................... 9
   2.3 Formation of scale inside calandria tubes ....................................................... 11
   2.5 Stages of scale formation ............................................................................... 13
      2.5.1 Initiation .................................................................................................... 13
      2.5.2 Transportation of species to the surface .................................................. 14
      2.5.3 Attachment ............................................................................................... 14
2.5.4 Detachment of species from the surface ................................................ 14
2.5.5 Aging of species...................................................................................... 14

2.6 Types of scale formation/fouling........................................................................ 14
  2.6.1 Crystallization fouling ............................................................................ 14
  2.6.2 Particulate fouling ................................................................................... 15
  2.6.3 Chemical reaction fouling ....................................................................... 15
  2.6.4 Corrosion fouling ................................................................................... 15
  2.6.5 Biological fouling ................................................................................... 15

2.7 How scale affects the function of evaporators................................................. 15
2.8 Factors affecting the rate of scale formation.................................................... 16
  2.8.1 Operating Parameters of the evaporators ................................................ 17
  2.8.2 Quality and the dosage of ingredients .................................................... 17
  2.8.3 Efficiency of clarification ...................................................................... 17
  2.8.4 Heat Exchanger design parameters ........................................................ 18
  2.8.5 Juice Quality and Process water quality ................................................ 18

2.9 Loss of heat transfer and resulting heat losses in evaporators ....................... 20
2.10 Scale reduction techniques........................................................................... 21
  2.10.1 Use of anti-scalant products ................................................................ 22
  2.10.2 Use high purity ingredients .................................................................. 22
  2.10.3 Conditioning of clear juice ................................................................... 23
  2.10.4 Use of electromagnetic apparatus ........................................................ 24

2.11 Mathematical modeling of evaporators and scale formation ....................... 25
  2.11.1 Energy Balance Equation ...................................................................... 26
  2.11.2 Specie Balance Equation ...................................................................... 26
  2.11.3 Modeling of scale formations .............................................................. 26

2.12 Summary of the literature Review .................................................................. 29

3. MATERIALS AND METHODS .......................................................................... 30
3.0 Introduction to materials and methods............................................................. 30
3.1 Experimental Methods .................................................................................. 30
  3.1.1 Sampling Procedure-Clear Juice and Syrup......................................... 30
  3.1.2 Sampling Procedure-Evaporator Scale............................................... 30
LIST OF FIGURES

Figure 1-1: Research Strategy.................................................................3
Figure 1-2: Conceptual Diagram of the research.................................4
Figure 2-1: Components of a single short tube evaporator...............10
Figure 2-2: Industrial Multiple Effect Evaporator..............................11
Figure 2-3: Calandria tubes of the evaporator with scale formation.....11
Figure 2-4: Percent components of Quintuple Effect Evaporators......12
Figure 3-1: Model of quadruple effect evaporator.............................33
Figure 3-2: Model of a single evaporator with scale formation...........34
Figure 4-1: Composition of Evaporator Scale – Factory 01..............44
Figure 4-2: Composition of Evaporator Scale – Factory 02..............45
Figure 4-3: Juice quality variation – Factory 01.................................46
Figure 4-4: Syrup quality variation – Factory 01.................................47
Figure 4-5: Calcium concentration variation in clear juice – Factory 01...48
Figure 4-6: Calcium concentration variation in syrup – Factory 01.......49
Figure 4-7: Juice quality variation – Factory 02.................................50
Figure 4-8: Syrup Quality variation – Factory 02.................................51
Figure 4-9: Calcium concentration variation in clear juice – Factory 02....51
Figure 4-10: Calcium concentration variation in syrup – Factory 02.....52
Figure 4-11: Scale thickness growth – Particulate Fouling.................53
Figure 4-12: Scale thickness growth-chemical precipitation...............54
Figure 4-13: Temperature variation-first evaporator.........................55
Figure 4-14: Temperature variation-second evaporator.....................56
Figure 4-15: Temperature variation-third evaporator.......................57
Figure 4-16: Temperature variation-forth evaporator..........................58
Figure 4-17: Variation of vapour flow rate with scale growth...............58
LIST OF TABLES

Table 2-1: Composition of Sugarcane Juice........................................19
Table 2-2: Mineral Composition of Sugarcane Juice...............................20
Table 2-3: Thermal conductivity of different materials..........................21
Table 2-4: Components of Carbide Sludge...........................................23
Table 2-5: Summary of mathematical models developed for scale formation
..................................................................................................................26
NOMENCLATURE

\( F \)  
Inlet juice flow rate (Tonnes/hr)

\( L_i \)  
Outlet juice flow rate (i=1 to 4)(Tonnes/hr)

\( V_i \)  
Steam/vapor flow rate (i=0 to 4)(Tonnes/hr)

\( x_i \)  
Brix% in juice (i=0 to 4)

\( m_i \)  
Mass inside the vessel (Tonnes)

\( T_i \)  
Boiling point temperature of juice. (i=0 to 4) (°C)

\( T_f \)  
Temperature of juice at feed. (°C)

\( T_s \)  
Temperature of steam. (°C)

\( U_i \)  
Internal energy. (kJ)

\( H \)  
Enthalpy. (kJ)

\( C_p \)  
Heat capacity of juice. (kJ/kg K)

\( \bar{H}_f \)  
Enthalpy of feed flow per unit mass. (kJ/kg)

\( \bar{H}_L \)  
Enthalpy of out flow per unit mass. (kJ/kg)

\( V_i \)  
Vapor flow rate from evaporator. (i=0 to 4)(kg/hr)

\( \lambda_i \)  
Latent heat of steam/vapor. (i=0 to 4) (kJ/kg)

\( Q_i \)  
Heat produce in evaporator. (kJ)

\( W_{ai} \)  
Mechanical work done. (i=1 to 4)(kJ)

\( \rho_i \)  
Density of juice inside evaporator 1. (kg/m3)

\( U_i \)  
Overall heat transfer coefficient

\( r_i \)  
Radius of calandria tubes (i=1 to 4)

\( t_i \)  
Thickness of scale on calandria tube (i=1 to 4)

\( n_i \)  
Number of tubes in evaporator (i=1 to 4)

\( h_{steam} \)  
Convective heat transfer coefficient in steam side
\[ h_{juice} \] Convective heat transfer coefficient in juice side

\[ R_{wall} \] Resistance to heat transfer from the wall

\[ R_{scale} \] Resistance to heat transfer in scale

\[ k_{wall} \] Thermal conductivity of calandria tube wall (kW/K)

\[ k_{scale} \] Thermal conductivity of evaporator scale (kW/K)

\[ A_i \] Heat flow area in calandria(i=1 to 4) (m²)

\[ A'_i \] Cross section area of tube inside calandria (m²)

\[ T \] Temperature (°C)

\[ p \] Purity (%)

\[ \mu \] Magnetic field strength

\[ E \] Induces Electric field vector

\[ B \] Magnetic field strength vector

\[ \omega \] Angular velocity of the current wave (rads⁻¹)

\[ s \] Line vector along the circumferential direction

\[ r \] Distance from the circumferential direction (m)

\[ a \] Acceleration to the particle

\[ k_d \] Deposition rate coefficient(hr⁻¹)

\[ k_{com} \] Consolidation Rate coefficient (hr⁻¹)

\[ C \] Concentration of particles in solution (kg/m³)

\[ k_{rem} \] Removal Rate coefficient (hr⁻¹)

\[ C_b \] Concentration of the substrate in the bulk fluid (kg/m³)

\[ C_e \] Equilibrium concentration of the substance at the conditions of the interface

\[ k_d \] Kinetic rate constant (hr⁻¹)

\[ n \] Order of reaction
γ  Evaporation rate (kg/hr.m²)