

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

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Degree of Master of Science in Sustainable Process Development

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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.



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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.

A.B.G.C.J. De Silva

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NOMENCLATURE

F	Inlet juice flow rate(Tonnes/hr)
L_i	Out let 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)
\hat{H}_f	Enthalpy of feed flow per unit mass.(kJ/kg)
\hat{H}_L	Enthalpy of out flow per unit mass.(kJ/kg)
V_i	Vapor flow rate from evaporator.(i=0 to 4)(kg/hr)
λ_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)
ρ_i	Density of juice inside evaporator 1.(kg/m ³)
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) (m ²)
A'_i	Cross section area of tube inside calandria (m ²)
T	Temperature (°C)
p	Purity (%)
μ	Magnetic field strength
E	Induces Electric field vector
B	Magnetic field strength vector
ω	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_{con}	Consolidation Rate coefficient (hr ⁻¹)
C	Concentration of particles in solution (kg/m ³)
k_{rem}	Removal Rate coefficient (hr ⁻¹)
C_b	Concentration of the substrate in the bulk fluid (kg/m ³)
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)



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