Modeling the Influence of Evaporation on Residual Chlorine in Water Storage Tanks using CFD

A case of National Water and Sewerage Corporation Water Treatment Plant- Jinja, Uganda

By

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DECLARATION

I Tulirinya John, hereby declare that to the best of my knowledge, this dissertation entitled 'Modeling the Influence of Evaporation on Residual Chlorine in Water Storage Tanks using CFD' is truly my original work and has never been submitted to any other university for the award of a degree or any other qualifications.

Signature..... Date.....

APPROVAL

This Dissertation entitled, 'Modeling the Influence of Evaporation on Residual Chlorine in Water Storage Tanks using CFD' has been submitted for examination with my approval;

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DEDICATION

I would like to dedicate this work to the Almighty God of Prophet David for his grace, favour, and wisdom that he has granted me, to my Father Mzee Ntumbu Joshua, my Mother Kiwala Rose, and all my brothers and sisters who have always strived to show me the true value of Education, my dear wife Kisakye Jesca, children and entire family, for all your support and inspiration.

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LIST OF ACROYNMS AND ABBREVIATIONS

CFD	Computational Fluids Dynamics
WST	Water Storage Tank
WTP	Water Treatment Plant
WDN	Water Distribution Network
WDS	Water Distribution System
BC	Boundary Conditions
FVM	Finite Volume Method
TOC	Total Organic Carbon
OpenFOAM	Open Source Field Operation And Manipulation
MULES	Multi Dimensional Universal Limiter with Explicit Solution
VOF	Volume Of Fluid
NWSC	National Water and Sewerage Cooperation
UV	Ultra Violet
DBPs	Disinfection By-Products
GNU	Gnu's Not Unix
RCl	Residual Chlorine
PLIC	Piecewise Linear Interface Calculation
PVC	Poly Vinyl Chloride

NOMENCLATURE

Symbol	Quantity	Units
V	Fluid velocity vector	$[ms^{-1}]$
C	Accommodation coefficient	
m	Mass of a molecule	$[kg]$
$\dot{m}$	Rate of mass transfer	$[kgm^3s^{-1}]$
M	Molar mass	$[kgmol^{-1}]$
p	Thermodynamic pressure	$[Nm^{-2}]$
p_rgh	Pressure excluding hydrodynamic pressure	$[Nm^{-2}]$
q	Heat flux	$[Wm^{-2}]$
S	Surface	$[m^2]$
T	Temperature	$[K]$
v	Specific volume	$[m^3kg^{-1}]$
V	Volume	$[m^3]$
α	Phase fraction	
ρ	Density	$[kgm^{-3}]$
κ	Curvature	
k	Thermal conductivity	$[Wm^{-1}K^{-1}]$
μ	Fluid viscosity	$[m^2s^{-1}]$
$\dot{m}_e$	Rate of evaporation	$[s^{-1}]$
η	First-order decay constant	$[s^{-1}]$
η_b	bulk decay rate constant	$[s^{-1}]$
η_w	wall decay rate constant	$[s^{-1}]$
c_p	Specific heat capacity	$[Jmol^{-1}K^{-1}]$

ABSTRACT

Water storage tanks are usually utilized in water distribution systems (WDS) to meet the water demand fluctuations. Long residence periods experienced in these tanks can cause immoderate loss of the disinfectant residual due to the numerous processes that occur in water. Low-level disinfectant residual can encourage microorganism regrowth in the distribution system, leading to unsafe water. Chlorine is the most common disinfectant used to disinfect water supplies. However, variations in the rate of chlorine decay in these storage tanks is one of the greatest limiting factors in ensuring adequate water treatment process and giving guarantee to its efficiency. These variations could be due to some inadequately tested mechanisms of chlorine reactions in bulk fluid, chlorine reactions with storage tank walls, and evaporation. This study presents Computational Fluid Dynamics (CFD) modeling approach to assess the influence of evaporation on residual chlorine in water storage tanks. Simulations together with experimental measurements were performed in laboratories as well as at the water treatment plant in order to gain a better understanding of the influence of evaporation on residual chlorine in water storage tanks. Findings from this study indicate that an increase in the evaporation rate accelerates the rate at which residual chlorine is lost. This study can contribute to the existing literature about monitoring chlorine decay in storage tanks and therefore help the managements of water and sewerage treatment plants to come up with appropriate tools and design of storage tanks. It is concluded that temperature is the main factor influencing evaporation, which in turn causes disappearance of residual chlorine within the water storage tanks.

Key words: Residual chlorine, water storage tank, bulk chlorine decay, wall chlorine decay, Evaporation.