UNIVERSITI PUTRA MALAYSIA

NUMERICAL STUDY ON EFFECT OF VORTEX GENERATOR FOR T-JUNCTION PIPE FLOW

HAMAD R DH A S ALAZEMI

FK 2019 149

NUMERICAL STUDY ON EFFECT OF VORTEX GENERATOR FOR T-JUNCTION PIPE FLOW

By

HAMAD R Dh A S ALAZEMI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

NUMERICAL STUDY ON EFFECT OF VORTEX GENERATOR FOR T-JUNTION PIPE FLOW

By

HAMAD R Dh A S ALAZEMI

August 2019

Chairman : Kamarul Arifin Ahmad, PhD
Faculty : Engineering

Application of Computational fluid dynamics (CFD) in studying T-Junction water pipe flow have been growing steadily. This is due to the fact that experimental work will cost more time and money. In Kuwait however, the CFD tool is not fully utilised in the T-Junction case due to lack experts to perform the CFD work. The current work focused on the CFD simulation on the T-Junction water pipe system that is available in Kuwait. The objective of the work is to investigate the fundamental physical mixing effects of the Kuwaiti T-Junction pipe and investigate the effects of the flow control device inside the T-Junction. The RANS equation was used as the governing equation. The standard k- epsilon model will be used for the turbulent flow of the water pipe. Second order discretization method was used to solve the non-linear RANS equations. The CFD results have been validated with the published experimental data with good agreement. From the baseline simulation, it is found that the physics of water flow shows that there is significant reverse flow at the downstream of the T-junction pipe. From the parametric study, three cases have been tested namely case with two vortex generators, four vortex generators, and eight vortex generators. From the results, it was found that the case with four vortex generators outperformed the other cases. The area of the reverse flow have been decreased significantly. Another parametric study was the size of the vortex generator. It was found that the best size was the 75 mm. The last parametric study was the magnitude of the water pipe flow. From the results, it was found that the vortex generator performed the best at the magnitude of 5m/s.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

NUMERIK STUDI PADA KESAN VORTEX GENERATOR UNTUK ALIRAN PAIP SIMPANG-T

Oleh

HAMAD R Dh A S ALAZEMI

Ogos 2019

Pengerusi : Kamarul Arifin Ahmad, PhD
Fakulti : Kejuruteraan

Penggunaan dinamik bendalir pengkomputeran (CFD) dalam mengkaji aliran paip air Simpang-T semakin berkembang. Ini disebabkan kerja eksperimen akan menelan belanja lebih banyak dari segi masa dan wang. Walau bagaimanapun, di Kuwait, alat CFD tidak digunakan sepenuhnya dalam kes Simpang-T kerana kekurangan pakar untuk melaksanakan kerja CFD. Kerja-kerja di dalam thesis ini memberi tumpuan kepada simulasi CFD pada sistem paip air Simpang-T yang boleh didapati di Kuwait. Objektif kerja ini adalah untuk mengkaji kesan pencampuran fizikal asas paip Simpang –T di Kuwait dan menyiasat kesan peranti kawalan aliran di dalam Simpang-T. Persamaan RANS digunakan sebagai persamaan penyelesaian. Model k-epsilon yang standard akan digunakan untuk aliran turbulen paip air. Kaedah berangka peringkat kedua digunakan untuk menyelesaikan persamaan RANS bukan linear. Keputusan CFD telah disahkan dengan data eksperimen yang diterbitkan dengan persetujuan yang baik. Dari keputusan simulasi, didapati fizik aliran air menunjukkan bahawa terdapat aliran terbalik yang signifikan di hiliran paip Simpang-T. Dari kajian parametrik, tiga kes telah diuji iaitu kes dengan dua penjana vorteks, empat penjana vorteks, dan lapan penjana vorteks. Dari hasilnya, didapati bahawa kes dengan empat penjana vorteks mengatasi keadaan yang lain. Kawasan aliran terbalik telah menurun dengan ketara. Satu lagi kajian parametrik adalah saiz penjana vorteks. Ia didapati bahawa saiz terbaik adalah 75 mm. Kajian parametrik terakhir adalah magnitud aliran paip air. Dari hasilnya, didapati penjana vorteks melakukan yang terbaik pada magnitud 5m / s.

ACKNOWLEDGEMENTS

First of all, I would like to thank my supervisor Prof. Ir. Dr. Haji Kamarul Arifin Ahmad, to guide me throughout the research work starting from selecting the title to the results. His massive knowledge, motivation and patience have given me more power and spirit to outrival in the research writing. I am also to thank Assoc. Prof. Ir. Dr. Faieza Abdul Aziz and Assoc. Prof. Dr. Rizal Zahari for their helpful supervision and advice. Thanks also to University Putra Malaysia in conducting this program while The School of Graduate Studies (UPM) for coordinating it.

Finally, to my wife thanks for your patience while I complete this study. Thanks also to my children, which serves as part of my inspirations in writing out this research. Also to my father and mother who always give me strength to complete this thesis. I dedicated this thesis to my wife, children and my parents.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Haji Kamarul Arifin Ahmad, PhD
Assosiate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Faieza Abdul Aziz, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Rizal Zahari, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
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LIST OF ABBREVIATIONS

AF	accelerating flow
ALE	arbitrary lagrangian eulerian
avg	average
BD	blended bifferencing
BF	boundary fitted
CD	central cifferencing
CFD	computational fluid dynamics
CPU	central processing unit
CT	computed tomography
CURVIB	curvilinear immersed boundary method
DES	detached eddy simulation
DF	decelerating flow
DFG	Deutsche Forschungsgemeinschaft (German Research Association)
DNS	direct numerical simulation
DWDN	Drinking Water Distribution Networks
EFD	experimental fluid dynamics
FCT	flux corrected transport
FD	fictitious domain
Fs	safety factor
FVM	finite volume method
GCI	grid convergence index
IB	immersed boundary
IIM	immersed interface method
IMM	immersed membrane method
LBM	lattice boltzman method
LES	large eddy simulation
LUD	Linear upwind differencing
MPI	message passing interface

MULES	Multi-dimensionsal limiter for explicit solution
NBF	non-boundary fitted
NBF-VOF	non-boundary fitted/volume of fluid
PDEs	partial differential equations
PF	peak flow
PIV	particle image velocimetry
PLIC	piecewise linear interface construction
RANS	reynolds average navier stokes
RBC	red blood cell
RC	right coronary
RSS	reynolds shear stress
WDN	Water Distribution Network

CHAPTER 1

INTRODUCTION

1.1 Overview

The WHO guidelines for drinking water quality states that, water free from turbidity, colour, odour, objectionable taste and at a reasonable temperature is said to potable water [1] [2]. The distribution pipelines in case of urban water supply need to monitored for contaminants such as microbial growth, internal corrosion of the pipes material and other deposits [1] [3].

Figures 1-1 and 1-2 show a typical urban water distribution setup and water treatment plant [4]. In GCC countries the majority of the water is supplied from the desalination plants [5]. Millions of Dollars' worth of water is wasted due to leakage [6]. A distribution network with leakage of less than 5% is said to be excellent. Leaks can be prevented by implementing leak detection techniques such as sounding method, leak noise correlation and gas tracing [6]. These methods are suitable for detection of leaks, utilising CFD techniques to predict and all together elimination of leaks can be achieved. The presence of halomethanes resulting from chlorination of dissolve matter in Kuwait water distribution network was studied by [7]. The water from public water distribution network and bottled mineral water was studied by [2]. They found that the public distribution network provided better drinking water quality compared to the bottled water. The major problems which arise from chemical contaminants is chronic renal issues. EPANET software by U.S. Environment.

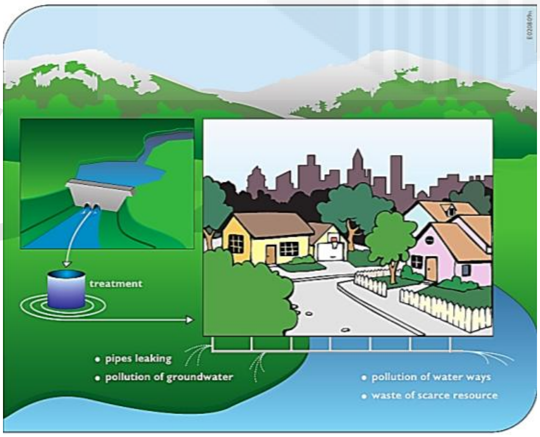

Figure 1.1: Typical urban water distribution setup [4]

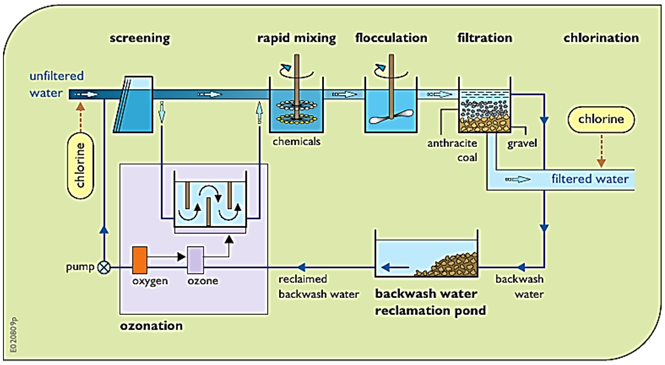

Figure 1.2 : Typical water treatment plant setup [4]

Protection Agency is widely used for modelling hydraulic and water quality [8]. Recent studies have shown that EPANET has drawn backs in predicting the mixing behaviour, thus the need for CFD.

Computational Fluid Dynamics (CFD) is a powerful engineering tool that can be used at the different stages of the water distribution networks development and operation. For example, during design stage, the CFD can be used to design the optimum setup or configuration of the system. As the CFD is a non-intrusive tool, therefore several important parameters can be tested on the system before the system is being constructed. The CFD tool has matured to the level where the results are reliable and can be used as basis for the real system.

One of the main effects of the water contamination is discolouration. Discolouration of the drinking water is due to presence of particles. These particles can come from two sources namely the external source and the internal source. The example of the external source can be from the water source, incomplete removal of solid particles at treatment plants, and particles added at the treatment plant for cleaning. Meanwhile the example of the internal source are the particles from pipes due to corrosion and bio film formations on the pipe wall. The internal or external sources increase turbidity and discolouration over a period of time. Biofilm formation leads to bacterial growth and results in degrading the quality of drinking water Liu et al., [10, 11]. Vreeburg et al., [12] also studied the effect of cast iron free pipe, on the build-up of sediments in WDN.

Other than water contamination, leakage is also the main problems in the water distribution network. Leakage is unintended phenomenon and therefore it is undesirable. Leak is usually defined as gradual loss of fluid (either gas or fluid). Water pipe leakage is normally associated with sudden change of pressure, crack, defects in pipes or lack of

maintenance [51]. In addition to the loss of water resources, the contaminant can be infiltrated into the piping system. Therefore, it is very important that this problem to be quickly detected and repaired.
Numerous experimental approach has been developed to detect the leakage. Among the traditional field tests are flow direction indicators, tracer gases, subsurface radar, earth sensitivity changes, infrared spectroscopy, microphones, and odorant and radioactive tracers. Meanwhile the latest leakage detection methods are developed which based on the system models, parameter identification and state observers, and also the state of the art of CFD.

Another important phenomenon related to water pipe flow is water hammer. Water hammer is an unintended sudden increase of pressure (pressure surge) or pressure wave in the piping system. It is caused by when a fluid or gas in motion is forced to stop or change direction suddenly. A detailed review by Ghidaoui et al. [61] on the history and current practise followed in modelling the water hammer effect.

Martins et. al., [62] performed 3D CFD to analyse the hydraulic transient flows in pressurized pipes using Computational Fluid Dynamics (CFD). They obtained the most efficient mesh size to model the pressurized water flow in pipes. The mesh uses minimum computation effort. The simulations were carried out realizable k-ε turbulence model. To simulate the water hammer effect the valve is instantaneously closed. This sudden closing of the valve causes a pressure surge. The velocity profiles, wall shear stress behaviours were plotted.

Other researchers conducted research works on the desalination water in Kuwait [95-100]. 95% of clean water of Kuwait came from the desalination process. As the cost of producing the desalinated water is expensive, therefore the problems of leakage, water hammer, and inefficient mixing should be avoided.

1.2 Problem Statement

A T-Junction is a common and an important part of the water piping distribution system. Its purpose is to either to distribute or to mix the water so that it can be utilised at further downstream of the pipe. Therefore it is important for the engineers to ensure the distribution or the mixing are efficient and optimised. One of the ways to ensure this to happen is through CFD simulations.

T-Junctions simulations are one of the most challenging CFD cases for the previous years. This is due to the fact that it is difficult to model the turbulence and the coupling of the turbulence and the flow's heat flux. In addition to that, the complexity of the reverse flow and the unsteady vortices increase the difficulty level of the CFD simulation. It is important however to obtain a simple solution for the CFD simulation so that it do not consume too many computing hours. Therefore, in the current study, it is proposed a simple RANS approach with common turbulence model to solve the T-Junction flow. It is hypothesized that the simulation is sufficient in terms of accuracy and flow details. The current study also proposed a flow control device namely vortex generator to reduce the reverse flow of the water pipe flows. The second hypothesis of the work is that vortex generator can optimized the distribution of the water pipe.

1.3 Objectives

1. To perform CFD simulation on the T-Junction water pipe system that is available in Kuwait
2. To investigate the fundamental physical mixing effects of the T-Junction pipe
3. To investigate the effects of the flow control device inside the T-Junction pipe scope of work

1.3 Scope Of Work

The current work focuses on the CFD simulation on the T-Junction pipe. Due to limitation in computing system, only RANS model was considered. The work implements the passive flow control device inside the T-Junction pipe system. The work focuses on the mixing and effectiveness of the flow control device in controlling the mixing.

1.4 Thesis Organization

Chapter 1 introduces to the background of water network system. It also highlights the motivation for the study, outlining the scope and objectives of the research.

Chapter 2 summarises the literature available on CFD studies related to T-Junction pipe. A detailed in-depth review has been carried out in this chapter. The chapter deals with various studies incorporating CFD to study the different parameters inside the T-Junction pipe environment.

Chapter 3 deals with the numerical methodology used for conducting the validation study. It also includes the numerical methodology followed to carry out the parametric study.

Chapter 4 reports the numerical, results. The validation and verification of the numerical results is reported. The results of the parametric study are also discussed.

Chapter 5 concludes the finding of the current work.

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BIODATA OF STUDENT

Hammad al asemi is a PhD student in Universiti Putra Malaysia. He works at the Kuwait Water Authority for the past 15 years. He handles residential water piping system for Kuwait City and overseeing the maintenance of the system. He has published 2 Scopus indexed journals and has presented 2 conference papers.

LIST OF PUBLICATIONS

Journals:

A. Hamad, S.M.A. Aftab and K.A. Ahmad "Application of CFD Techniques in Piping Distribution System and Special Focus on the Arabian Peninsula: A Review", International Review of Mechanical Engineering (IREME), 2018. (Under Review)

A. Hamad, S.M.A. Aftab and K.A. Ahmad, "Reducing flow separation in T-junction pipe using Vortex Generator: CFD study", Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, Volume 44, Issue 1, 1 April 2018, Pages 36-46

Conference Proceedings:

A. Hamad, S.M.A. Aftab and K.A. Ahmad "Reducing Flow Separation in T-Junction Pipe Using Vortex Generator CFD Study", ICCMEH-2017, 19-20th December 2017 at Manipal Institute of Technology, Manipal, India.

A. Hamad, S.M.A. Aftab and K.A. Ahmad "Review on Application of CFD Techniques in Piping Distribution System for Residential Clean Water Supply", ICCMEH-2016, 17-18th December 2016 at Kyushu Institute of Technology, Kitakyushu, Japan.

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