Development of Aerator for Water Saving

Hasnol M.Z.* and Ahmad Zaharuddin M.F.

School of Mechanical Engineering, Faculty of Engineering,
Universiti Teknologi Malaysia,
81310 UTM Johor Bahru,
Johor, Malaysia

*Corresponding email: zakariyamuhammed180@gmail.com

Article history
Received
5 January2020
Revised
23April 2020
Accepted
1 June 2020
Published
15 June 2020

ABSTRACT

*Global technology keepson improving continually from time to time especially in product design and development. In this work, a proposed spray aerator design was implemented in an effort to adopt an initiative related to the water savingpolicy. This paper presents an experimental method of evaluation to develop the aerator used in ablution (wudhu' in Islamic practice) to improve the water saving activity. Results showed that the proposed aeratordesign improved the water efficiencyof the flowrate by 88% compared tothe earlier design and deemed to have more potentials to obtain higher economic benefits. The improveddesign managed to reducethe water flowrate and consumption at a desirable level. The recorded data provided information on the duration and volume of the water consumption per use and it was deemed helpful in evaluating the human behaviour during ablution. The study also highlights the fabrication of the aerator using polymeric materials with the aid if a 3D printing process. The results were acquired from the simulation and later analysed using theANSYS FLUENT Version 19.2 software. Finally, the optimum conditions for promoting the effectiveness in term of saving is to support the water management activities were established, taking into account the beneficial role of water consumption***.**

Keywords: *Water saving, product development, water separator, aerator, ablution*

1.0 INTRODUCTION

Basically, water is a natural treasure that is priceless, it is a necessity to live as it is an important source in generating various economic areas such as agriculture, industry, power generation and so forth. In the world today, it is uncertain about the state of the water crisis globally. According to the United Nations, water of around two billion human or nearly a fifth of the population worldwide, living in areas of water shortage [1]. It is expected that by 2025, more than three billion people will live in a water-stressed country and as many as 17 countries will slip their classification from water pressure to water shortages [2].

On average based on the users of South East Queensland Residential, water use in a household uses approximately 80 gallons of water per day from pipelines [3]. One of the sub-scopes of the present research is to produce an aerator that can provide water saving when the water is discharged from the faucet.

The aerator can be attached to the faucet and can be in a spray mode. The flow of water into inner cavity and creates a spray mode. The next method is to provide a reduction in the water flow that has an orifice reduced through the cavity. Basically, the aerator is expected to make some changes to the users in terms of ways and means to efficiently consume water and energy. In other words, there should be an easy way in the improved aerator design that can lead to water saving by upgrading the usual flow of tap aerator into the saving mode of this new aerator design.

In addition, the study also highlights a number of water saving measures that were implemented in different countries. Thus, the study was deliberately carried out to show the effectiveness of the proposed aerator design for water saving. This effort should be well promoted with the water saving measures in order to support the green policy and global sustainability. It is the part of the water saving and sustainability initiatives that is indeed deemed as an important factor in improving one’s live. Reducing the water usage has a high impact and potential for water saving and indirectlycontinue to elevate own benefit of the available resources.

In 2012 United Nations World Water Development report, 80 percent of the world waste water is not collected or treated [4]. With the modern irrigation system that focuses on water consumption measure with water flow meters installed, it is desirable that it can minimize significant amount of water wastage [5]. Thus, this study emphasises on the design and development of an aerator for water saving. A simulation method employing CFD was utilisedin designing the contour map of the output water flow pattern in the systemwhile an analysis of variance was carried out to determine the significant factors that affect the relative pressure and velocity magnitude factor of the selected hole size of aerator.

2.0 LITERATURE REVIEW

2.1 Water Footprint

This study discusses the water footprint in which the strugglefor freshwater resources has increased for decades due to the population and economic growth, rising demand for agricultural products for food/non-food use and transitional in meat and sugar-based products [6]. Most authors have estimated that our reliance on water resources will continue to increase significantly ahead. Furthermore, it also affects food safety and sustainability in the environment. Approximately 97% of our raw water is supplied to the agriculture, domestic and industrial sectors needed to be supplied from river drainage [7]. A report estimated that the global water production will increase from 4500 billion m^3/year to 6900 m^3/year by 2030 [6].

The environmental policy in Malaysia still lags behind compared to other pressing issues for industrial development [2]. Therefore, good water governance is needed in Malaysia in order to handle the water problem complexity for efficient water management and ensuring the economic, social and environmental sustainability as well. The WWF-Malaysia urges people to practice good water sustainability, be more conscious of water usage and wastage and thus geared towards reducing the collective water footprint [8, 9].

According to Han*et al*. (2008) it is also no exception in Korea to accept this water management challenge [10]. In the past, the country has achieved a somewhat surprising economic growth rate with an annual rate of Gross Domestic Product (GDP) of 8.5% [9]. This indicated that the current water policy needs to be changed [8]. The overdue water allocation system adds conflict to consideration of the importance of water to stakeholders [11].

2.2 The Ablution - *Wudhu’* in Islamic Practice

The most appropriate translation for *al-wudhu’*(in Arabic) is ablution [12]. Ablution is a ritual of washing performed by a Muslim and it is part of the compulsory activities to ensure cleanliness and holiness before he/she performs the prayer (solah) [13]. It is reported in a hadith that the ***Prophet Muhammad SAW***said that cleanliness is half portion of faith (*iman*).

Based on the Islamic historical records, ***Prophet Muhammad SAW*** used one *mudd* of water to perform ablution as reported by *Bukhari* and *Muslim*. A *mudd*is equivalent to about 0.544*l* of water [14]. Based on the experiment during ablution activity, it was found that about 3-7*l* of water per person was typically used during ablution [15].

2.3 Working Principle of the Spray Mode

For a median droplet (diameter)to specify the drop size distribution, theresultant spray, can be divided the into two equal parts in terms of the number, length, surface area, or volume [16].

Most notably, the drop-size distribution and characteristic diameter of the spray yield to a clear representation of the atomization degree [17]. This choice is commonly applied in the single-phase flow analyses comprising a discrete number of articles related to bubbles, droplets, pollutants, etc. [18].

2.4 Simulation

The water flow in the pipeline and out of aerator also takes into account the interaction with the surrounding air and its motion tendency to drag the proper spray and mist. Water discharge presents a consistent output with the solid-cone nature of the spray with the large droplets.The cone angle tends to decrease as the axial distance from the orifice increases; this trend was expected and is consistent with the classical theory on sprays produced by pressure atomizers.

3.0 EXPERIMENTAL PRODUCT DEVELOPMENT

Figure 1 shows the implementation of the undertaken research in which it begins with the initial design process leading to the fabrication of the physical aerator at Stage 1 and later proceeds until the aerator development at Stage 3 which is the final product. The research implementation also covers both the simulation and experimental methodsto study the behaviour of the aerators in producing the water discharge flow pattern. In order to study the contour map produced at the aerator related to its dynamic behaviour, this methodology utilised the*ANSYS FLUENT version 19.2* software in the simulation to visualise the water spray pattern.

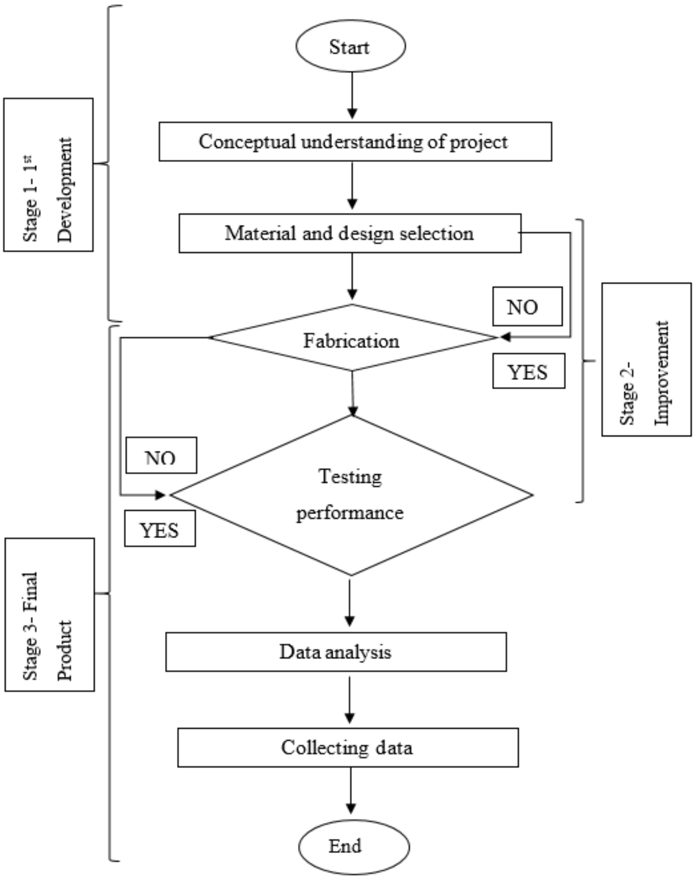
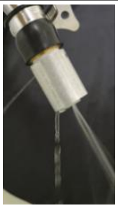


Figure 1: Flowchart showing the development and implementation of the related research activities

3.1 Stage 1: Initial Development of the Aerator

The experimental procedures were developed right from Stage 1 involving the fabrication of the product until Stage 3 that is related to the final product. The practical activity begins with the machining process involving cutting the cylinder bars to size and drilling holes using the lathe and drilling machines. Note that all results obtained from the experiments were recorded for analysis. Table 1 presents the results of the water discharge after fabrication (machining process) to observe and analyse the water flow.

Table 1: Water discharge after fabrication of the aerator for Stage 1 according to various hole sizes

Hole size (mm)	**3**	**2**	**1**	**0.8**	**0.4**
Water discharge (*l*/m)					

It is the main aim of the study to achieve 50% less water consumption or water saving. In order to complete the experiments, the water pressure needs to be tested, thereafter requiring a pressure gauge (sensor) that typically measures the parameter of the water flowing in a pipeline. For the experiment, a water pressure of around 1.5 bar was chosen because this is deemed as most convenient and applicable to all general conditions.

3.2 Stage 2: Product Improvement

In delivering of the product, the emphasis is on the engineering design capabilities. The idea is to produce more quality products that can reach the market from beyond the competitors. This situation looks feasible but the task is not easy in practice. For this improvement, the streamflow pattern of the water discharge specifically for the1 mm hole size aerator needs to be improved. From here, it can be speculated whether the design can produce significant improvement or otherwise. Next, the proposed material to be used in the design was selected using a polymeric based material, i.e., *polyethylene* due to its particular ease of fabrication using lathe and milling machines. Subsequently, the resultsbased on the application of a wide spread angle of water discharge related to a new slotted design can be observed and analysed.

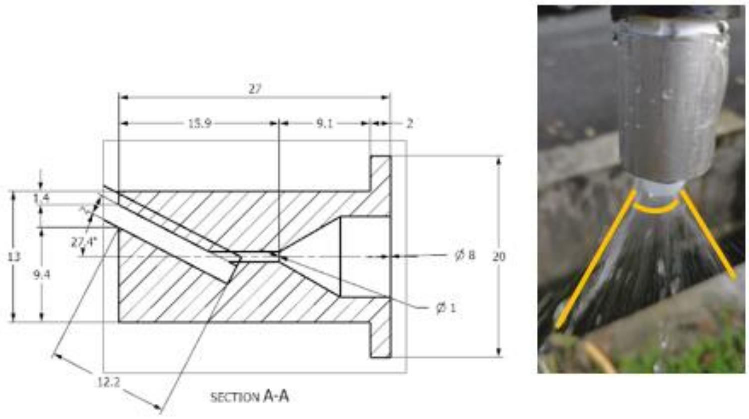


Figure 2: Side view of slotted design and wide spread angle from the aerator

3.3 Stage 3: Final Product

In Stage 3,it was emphasised that even at the conceptual design phase that a good design should take into account the long-term development of the product that produce good and efficient results based on the proposed improved design that leads and conforms to the user satisfaction.The proposed design should be developed to ensure that it fully meets the established evaluation to continuously monitor its performance and ensure that it conforms to the current and evolving best design practices. For the material used in the product design during the fabrication phase, *acrylonitrile butadiene styrene* (ABS) plastic was used and fabricated using a 3D printing method due to its ease of use and the fact that the machine requires less maintenance. The schematics and CAD drawing of the new proposed (final) design would give the expected result in terms of improving the wide spread angle of water spray discharge as shown in in Figure3 for the water separator component and Figure4 for water volume control.

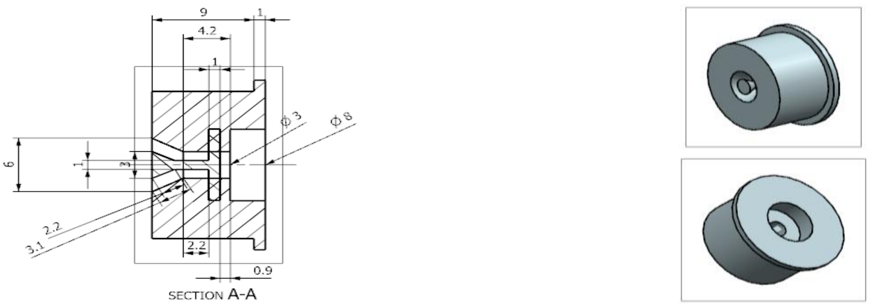


Figure 3: Side view and isometric drawing of the water separator of the aerator

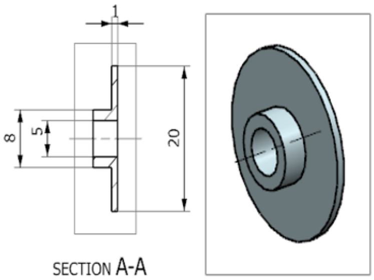


Figure 4: Side view and isometric drawing of the volume control of the aerator

4.0 RESULTS AND ANALYSIS

The preliminary test was initially conducted to obtain the measurements related to Stage 1 phase based on different hole sizes developed as the design was specifically done to allow for comparison of the performance to determine the influence of the hole size on water flow. At first the water flow without aerator was set to 20.912 *l*/m but later, different readings were taken to observe the water discharge from the aerator and other results based on various settings, the main aim of which is to reduce the water flowrate.

4.1 Stage 1: Development of Aerator

Noticeably, since an increase in the aerator hole diameter leads to an increase in water flow (or water discharge), this eventually decreases the directional of volume flowrate which further reduced the water available capacity. A steady rise of the water discharge can be clearly seen in the differences of the water flowed from an aerator based on the hole size.

Table 2: The performance of water discharge in Stage 1 for different hole sizes

Hole size (mm)	**3**	**2**	**1**	**0.8**	**0.4**
Water discharge (*l*/m)	5	2.5	0.6	0.32	0.15
Percentage usage (%)	25	12.5	3	1.6	0.8
Percentage reduction (%)	75	87.5	97	98.4	99.2

Just over half of the water at 2.5 *l*/m was dischargedfora hole size with diameter 2 mm, whereas for a 3 mm diameter, it rose significantly to 5 *l*/m which is deemed at the highest water level reading. The higher amount of water % reduction has been attributed to the nature of sizing that requires the aerators to have smaller diameter formore efficient performance.

Comparably, the lowest percentage usage is due to the smallest size being used whileperforming the experiment. At 3mm hole size, the reduction has almost trebled to a significant 75% compared to a mere 25% in the percentage usage of initial water flow. There was also a considerable increase of up to 12.5% of the percentage usage and both reaching 98% and 99%, respectively in terms of the percentage reduction.

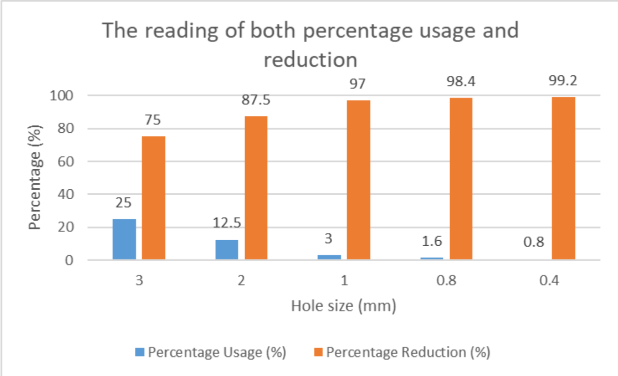
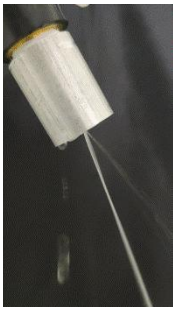


Figure 5: Percentage of usage and reduction of water consumption

4.2 Stage 2: Product Improvement

Table 3 shows the comparison of the performance between Stages 1 and 2 for different designs at the aeratoroutputs. The results indicate that there was no distinct advancement with regards to the showthe improved performance. The only significant difference lies in the variance of the two inner designs at the aeratoroutlet, i.e., it only exhibits a slight improved advancement with regards to its fabrication. The results show that the slotted aerator type produces a wide-angle water spray. The shape and pressure changes in the design affect the width of the spray pattern yielding a more extended range of the angle. It is expected that in order to get the best result while taking *wudhu'* using the slotted aerator is better than using the standard hole counterpart due to the extra wide angle sprays it produced.

Table 3: Comparison of the performance between Stages 1 and 2

Hole size (0.8mm)	Standard hole	Slotted
Percentageusage (%)	3	2.35
Percentage reduction (%)	97	97.65
Image of aerators		

4.3 Stage 3: Final Product

All aeratorsexhibit superior performance from Stages 1 to 3 in order to get best minimal water discharge in-line with the research objective. The result shows that the water discharge for Stages 1 and 3 is 5 *l*/m and 2.5 *l*/m, respectively as shown in Table 4 and Figure 6. This shows significant decrease of output of about 50%. The good performance can be attributed to the measures taken to improve the aerator design.

Table 4: Results of Stages 1 and 3

Hole size (3 mm)	Stage 1	Stage 3
Water discharge (l/m)	5	2.5
Percentage usage (%)	25	12
Percentage reduction (%)	75	88

Image of aerators		

Meanwhile, Stage 3 shows good results in terms of the percentage usage of about 12% from 25% in Stage 1, again showing a 50% improvement. Besides, the final aerator design also shows improved aesthetic appearance.

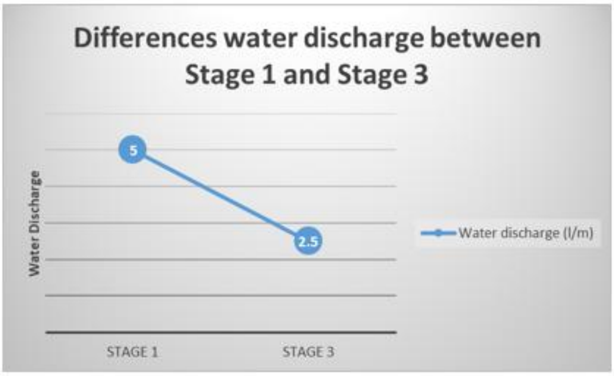


Figure 6:Line graph of water discharge of Stages 1 and 3

4.4 Simulation of Water Discharge atStage 3

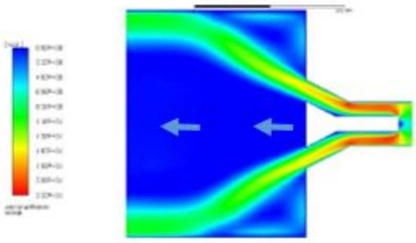
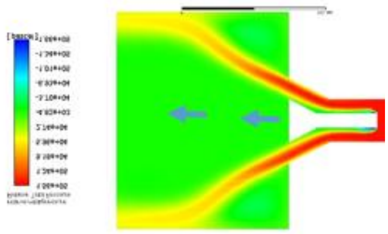
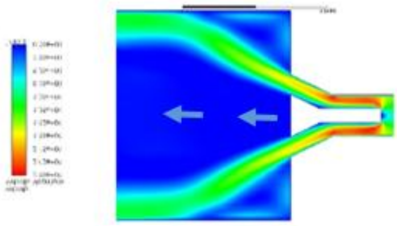
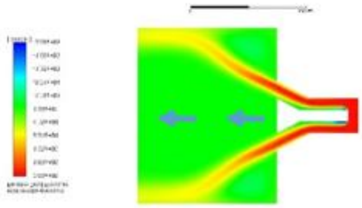
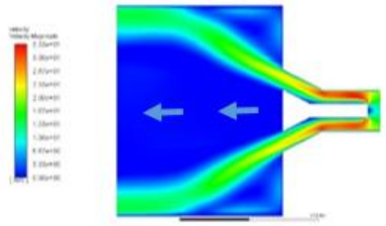
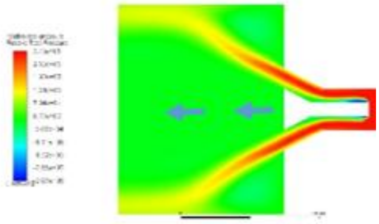
This wasdeliberately conducted for Stage 3 with the generating parameters of the aforementioned conditions. This is in-line with the typical procedure that is commonly applied to a single-phase flow analysis involving a discrete number of particles such as bubbles, droplets, pollutants, etc. [10]. In the present case, the water droplets released at a pressure of 1.5 bar are deemed sufficientto create the shape tracking particle. Table 5 shows the magnitude of the reference velocitiesin the water flow according to three different maximum operating pressures in the system.

Table 5: Water flow against pressure

	Operating pressure		
	1.5 bar (max)	2.0 bar (max)	3.0 bar (max)
Velocity magnitude, v_{ref} (m/s)	23.15	26.95	33.33

At a glimpse, there were no changes on the color of the contour map as shown in Table 6, yet a slight increase of the phase difference between these parameters can significantly change the relative and magnitude of the water flow.

Table 6:The contour maps of the velocity magnitude and relative pressure

Operating pressure(bar)	Contour map	
1.5		
2.0		
3.0		

5.0 CONCLUSION

In conclusion, the proposed aerator design is expected to improve and producethe optimal output water flow for reducing the water consumption during ablution. In addition, the design helps to reduce the accumulation of dirt in the pipe at the output section. It is obvious that the aerator provides higher output throughout its active operation compared to the performance of an aerator without the proposed design. However, it is evident that in order for the aerator to draw its full potential involving the water discharge, more parameters need to be considered apart from the flow rate and pressure range.

ACKNOWLEDGMENTS

The authors would like to express their sincere appreciation to the Centre for Community and Industry Network (CCIN) for funding the research.

REFERENCES

1. Guppy L. and Anderson K, 2017. *Global Water Crisis: The Facts*, United Nations University Institute for Water, Environment and Health, Retrieved from: https://inweh.unu.edu/wp-content/uploads/2017/11/Global-Water-Crisis-The-Facts.pdf. [Accessed on 12 November 2019].
2. World Resource Institute, 2019. *17 Countries, Home to One-Quarter of the World's Population, Face Extremely High Water Stress*, Retrieved from: https://www.wri.org/blog/2019/08/17-countries-home-one-quarter-world-population-face-extremely-high-water-stress. [Accessed on 12 November 2019].
3. Beal C., Stewart R.A., Huang T. and Rey E., SEQ Residential End Use Study Water, *Journal of the Australian Water Association*, 38 (2011): 80-84.
4. Seametrics, 2015. *5 Growing Trends in Water Conservation*, Retrieved from: https://www.seametrics.com/blog/water-conservation-trends/. [Accessed on 12 November 2019].

5. Nair S., George B., Malano H., Arora M. and Nawarathna B., 2014. Water–energy–greenhouse Gas Nexus of Urban Water Systems: Review of Concepts, State-of-art and Methods, *Resources, Conservation and Recycling*, 89: 1–10.
6. Hoekstra E.E., 2014. Water Footprint Scenarios for 2050: A Global Analysis, *Environment International*, 64: 71-82.
7. Saimy I.S. and Mohamed Yusof N.A., 2013. The Need for Better Water Policy and Governance in Malaysia, *Procedia-Social and Behavioral Sciences,* 81:371-375.
8. Mohamad S., 2017. *Saving Water in the Quest to Secure the Future*, Retrieved from: http://www.wwf.org.my/?24665/Saving-Water-in-the-Quest-to-Secure-the-Future. [Accessed on 11 October 2019].
9. Fang K., Zhang Q., Yu H., Wang Y., Dong L. and Shi L., 2018. Sustainability of the Use of Natural Capital in a City: Measuring the Size, and Depth of Urban Ecological and Water Footprints, *Science of the Total Environment*, 631-632: 476-484.
10. Han S-Y., Kwak S.J. and Yoo S-H., 2008. Valuing Environmental Impacts of Large Dam Construction in Korea: An Application of Choice Experiments, *Experimental Impact Assessment Review*, 28:256-266.
11. Moore M-L.,von der Porten S., Plummer R., Brandes O. and Baird J., 2014. Water policy Reform and Innovation: A Systematic Review, *Environmental Science& Policy*, 28: 263-271.
12. Kamal A.M., 2008. *Fikih Thaharah*, Jakarta Timur.
13. Anom Besari A.R., Rachmat A., Zamri R., Ahmad Y., Palil M.D., Prabuwono A.S., 2009. *Automatic Ablution Machine using Vision Sensor, 2009 IEEE Procs. of Symposium on Industrial Electronics and Applications (ISIEA 2009)*, 1: 506-509.
14. Mamun A.A., Muyibi S.A., Aremu S. and Abdul Razak N.A., 2014. Treatment of Used Ablution Water from IIUM Masjid for Reuse, *Advances in Environmental Biology*, 8(3): 558-564.
15. Zaied R.A., 2016. Water Use and Time Analysis in Ablution from Taps, *Applied Water Science*, 7: 2329–2336.
16. Merci B., Roekaerts D. and Sadiki A., (Eds.), 2011.Experiments and Numerical Simulations of Turbulent Combustion of Diluted Sprays, *Procs. of the 1st International Workshop on Turbulent Spray Combustion*, Corsica, France.
17. Lefebvre A.H., 1989. *Atomization and Sprays*, Hemisphere, Washington, DC, USA.
18. Raffel M., Willert C. and Kompenhans J., 1998. *Particle Image Velocimetry*, Springer, Heidelberg, Germany.