

# Investigation on Convergence – Divergence Nozzle Shape for Microscale Channel in Harvesting Kinetic Energy

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**Abstract.** This paper presents performance evaluation of nozzle shapes on microscale channel by employing different types of NACA airfoils profile and conventional profile. The deploying nozzle used are NACA 0012, NACA 0021 and NACA 0024 airfoils while for conventional convergence-divergence nozzle diameter ratio ( $d_2/d_1$ ) in the range from 1/4 to 3/4 are applied. These nozzles are assembled on rectangular cross sectional microscale channel which has designated constant fluid flow velocity at the channel inlet. This study revealed reduction on diameter ratio increased dramatically fluid velocity but further reduction on diameter ratio exposed fluid flow to fluctuate which slightly slowing down the fluid velocity. Nevertheless, curved NACA profiles are favourable for convergence – divergence nozzle in microscale channel as it significantly improved flow characteristics by enhancing fluid velocity and resultant kinetic energy as compared to conventional profile.

## 1. Introduction

The sustainable energy has been a point of interest for the researchers, due to the level of greenhouse effect and the fuel cost dilemma. Renewable energy is an efficient solution for the future to accomplish a perfect connection between renewable energy and economic improvement [1]. Small-scale hydro or micro-hydro power has been increasingly used as an alternative energy source which produces clean power resource, especially in remote areas where other power sources are not available [2]. Instream innovation is a small scale hydro-plant system and it depends on the hydrokinetic turbines in waterways or canal to produce energy. Usually, these systems do not require a huge infrastructure like dam or major water diversions, but by water wheels which reduce environmental impacts [2]. Harnessing kinetic energy from streaming water can optimize existing facilities [3]. For past years, researchers have been interested in the use of hydrokinetic turbines in stream of waterways, trench or channel to create power because of the greenhouse gas emissions and the fuel cost crisis. Numerous countries that are surrounded by watering system or rainy channels have a great potential for building up this innovation [4]. These countries have a primary issue for the advancement of hydrokinetic turbines which is low velocity of flow occurs in open flow microscale channel. An idea to increase the channels current flow is to set up nozzle in open channels.

The nozzle was considered to have the capability of intensifying the flow direction at the same time increasing the flow velocity. Based on research, it is found that the nozzle performance is important which feature the interactions of nozzle geometry and kinetic energy produce. Performance of nozzle can be explained as failure such as velocity of water loss and inconsistent flow of water produce occur

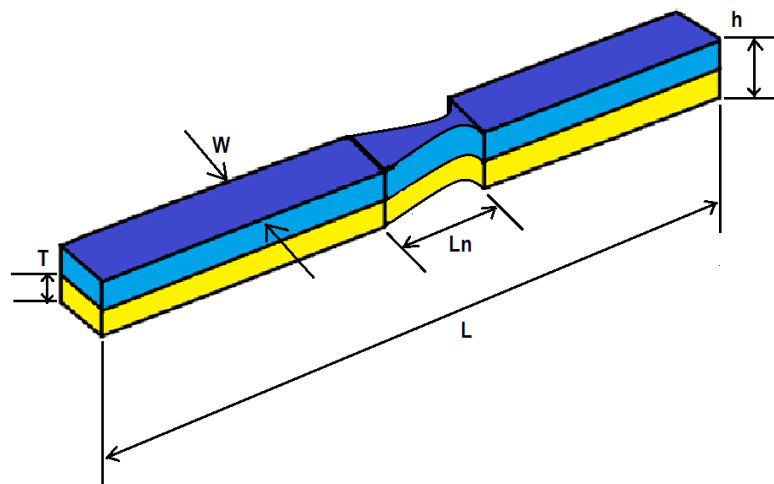


on the nozzle which lead to incapability for the nozzle to generate energy. During harnessing energy from flowing water, there are a few problems that occur. The conventional nozzle that is commonly used in hydrokinetic plant is insufficient as in low velocity flowing water, the kinetic energy captured is limited. Moreover, the conventional nozzle loss high kinetic energy at high velocity due to turbulence flow in the stream. Nozzle geometry which are nozzle shapes and diameter ratio influence the performance and characteristics of the flow in the rectangular microscale channel [5]. As nozzle geometry is vital factor in capturing energy in flowing stream and its alteration contribute to massive enhancement thus it is important to study on how the nozzle performance affected by the nozzle geometry. The focus of the study is the effect of the nozzle geometry in a rectangular microscale channel on nozzle performance in the aspect of kinetic energy.

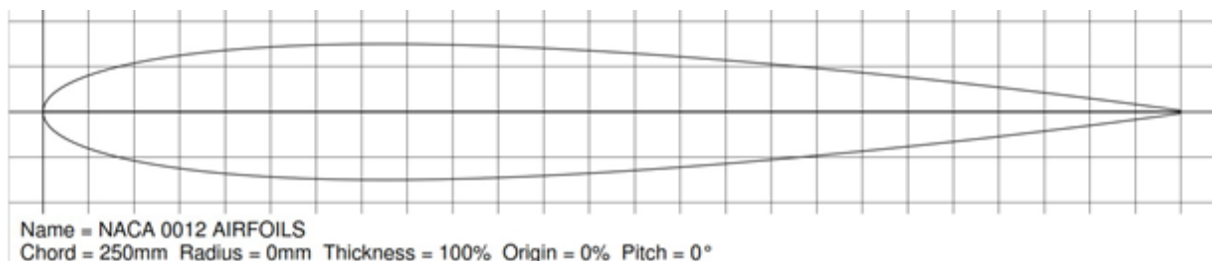
## 2. Design of microscale channel

### 2.1. Configuration of microscale channel

The shape of the microscale nozzle channel design is shown in Figure 1 where  $L$  shows the overall length of channel,  $W$  is the width of the channel,  $T$  is the inlet water level, and  $h$  is the channel depth. The channel has rectangular cross section. The nozzle was deployed in the middle of the channels which  $L_n$  is the length of nozzle. NACA Four-Digit Series is the first family of NACA airfoils. NACA Four-Digit Series consists of 4 digits e.g. NACA 0012, which label the camber, position of the maximum camber and thickness [7]. For example, the NACA 0012 airfoil has a maximum thickness of 12% of chord length. The geometry of NACA 0012 is shown in Figure 2.

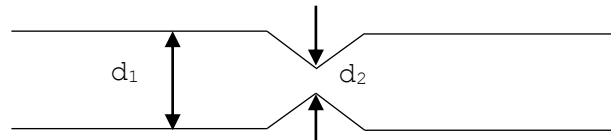


**Figure 1.** Microscale channel configuration



**Figure 2.** Cross Section of NACA 0012 [7].

Conventional nozzle used in this study for comparison to NACA nozzle is convergence - divergence system. In convergence – divergence nozzle, geometry difference between the conventional nozzles is the diameter ratio between the nozzles. Figure 3 shows dimension notation of  $d_2 / d_1$  in convergence-divergence nozzle in which  $d_2$  is diameter of nozzle and  $d_1$  is width of channel.

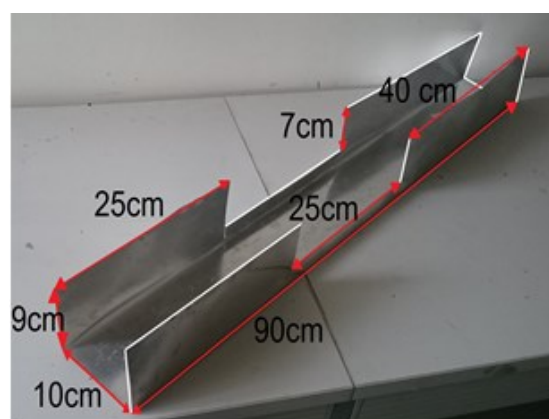


**Figure 3.** Conventional convergence - divergence nozzle

## 2.2. Experimental work

Microscale channel is fabricated internally which it can fit every nozzle employed in this study. The channel is made by aluminium thin sheet by forming it to rectangular cross section. The nozzles are placed at the slits on channel. For easy access, slits have been made at the bottom part of the nozzles to allow the nozzles be replaced with another nozzles with ease. NACA based nozzle are fabricated by using styrofoam. In order to harden the finished styrofoam, a polystyrene putty is used and sandpapers of different grade are used to smoothen the airfoils profile. Figure 4 exhibits a complete microscale channel used in conducting the experiment.

The inlet water velocity is set to constant velocity throughout the experiment. Velocity of the fluid stream is measured to determine kinetic energy produced consequent of accelerating fluid stream at the end of nozzle. In Table 1 it shows parameters for each nozzle applied in the experiment. The nozzles are assembled to microscale channel 40 cm from the channel inlet and a turbine is installed definitely at the end of nozzle to measure fluid stream velocity. Fluid stream velocity measurement is based on revolution of turbine rotation from the accelerating of fluid flow.



**Figure. 4.** Microscale channel

### 3. Mathematical equations

The following equation is used in calculating the fluid velocity.

$$v = \omega r \quad (1)$$

$v$  = velocity, m/s

$\omega$  = angular velocity, rad/s

$r$  = radius of turbine blade, m

The radius of the blade is 7.5cm (0.075m) and angular velocity is acquired directly from turbine speed.

From the velocity measured, the kinetic energy produced by each configuration of respective nozzle is calculated accordingly.






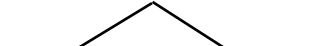
$$K_e = \frac{1}{2}mv^2 \quad (2)$$

Continuity equation (3) is applied to calculate mass flow rate through the nozzle inlet.

$$m = \rho v A = \rho v_1 A_1 = \rho v_2 A_2 \quad (3)$$

where  $\rho$  is density of water and A is cross sectional area of the flow.

**Table 1.** Nozzle Parameters

Nozzle	Profile	Parameter
NACA 0012		$d_2/d_1 = 0.76$ $L_n = 0.25$ m
NACA 0021		$d_2/d_1 = 0.58$ $L_n = 0.25$ m
NACA 0024		$d_2/d_1 = 0.52$ $L_n = 0.25$ m
Conventional convergence - divergence		$d_2/d_1 = 1/4$ $L_n = 0.25$ m
		$d_2/d_1 = 1/2$ $L_n = 0.25$ m
		$d_2/d_1 = 3/4$ $L_n = 0.25$ m

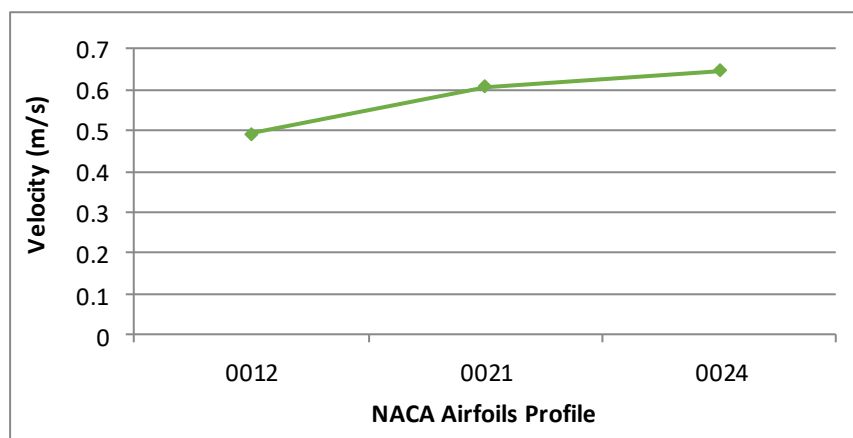
#### 4. Result and discussion

Nozzle profile itself enable it to control the direction and characteristics of a fluid flow. This is due to the nozzle inner structure, especially during choking process at the throat. The flow is obstructs and compress during choking. The flow from the inlet section accelerates at the throat then decelerates through the outlet section. The concept of convergence-divergence nozzle employed both on NACA and conventional nozzle is proven offer good performance as it increased the mean velocity across nozzle [3] since this system capable to develop flow pattern properties behind the nozzle. Based on the graph in Figure 5, NACA 0024 produced the highest velocity which is 0.65 m/s while NACA 0012 has the least velocity 0.5 m/s produced as expected. By referring to continuity equation (3), velocity will increase as the area of contraction decreased. Since NACA 0024 has the maximum thickness, thus it has resulted in the lowest contraction area. Consequently NACA 0024 profile accelerated the fluid flow stream to the highest value.

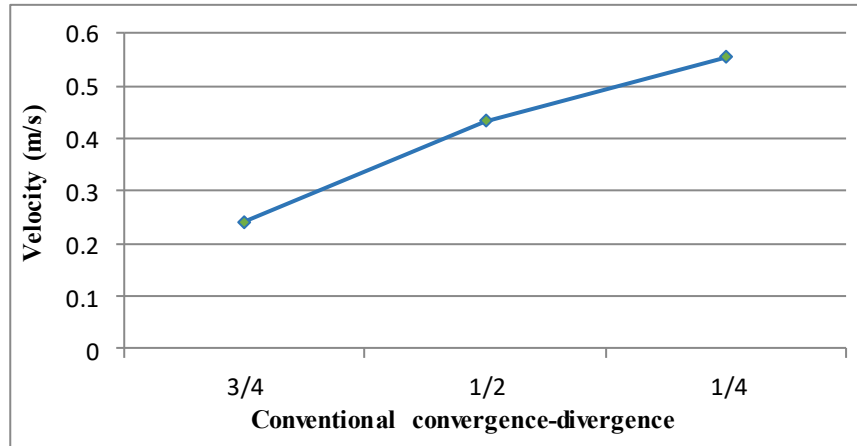
Meanwhile for convergence – divergence nozzle, the maximum velocity produced is 0.554 m/s for diameter ratio  $1/4$  as depicted in Figure 6. When the diameter ratio increase by 25%, the resultant velocity reduced to 0.43 m/s. The principle lie on the nozzle concept which is effect of back pressure has contributed to this phenomena. Back pressure at the nozzle outlet is decreased when the diameter at choking area increase hence reducing the resultant velocity. The trend line for both NACA profile and convergence – divergence profile are proportionally linear which aligned with continuity equation. Nevertheless, both graphs in Figure 5 and Figure 6 exhibit slight reduction in velocity on further decreasing of diameter ratio specifically on NACA 0024 and  $1/4$  diameter ratio respectively. It occur due to increasing of turbulence intensity behind the nozzle [5] which lead to friction loss and slowing down the fluid velocity. In Table 2 it presents comparison of diameter ratio to resultant velocity between NACA nozzle and convergence – divergence. It is obviously shows NACA profile nozzle capable of accelerating the fluid flow in microscale channel more than 30% as compared to conventional convergence – divergence nozzle.

**Table 2.** Velocity comparison for similar diameter ratio

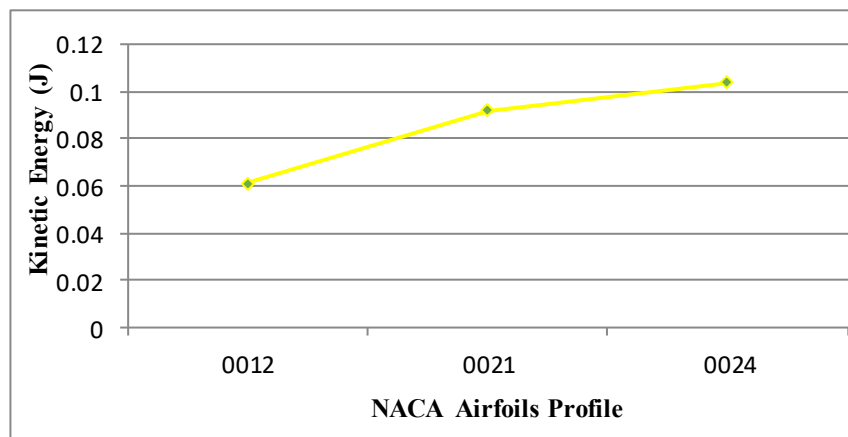
Diameter ratio $d_2/d_1$	Velocity (m/s)
$3/4$	NACA 0012 = 0.493 Convergence - divergence = 0.241
$1/2$	NACA 0024 = 0.646 Convergence - divergence = 0.433



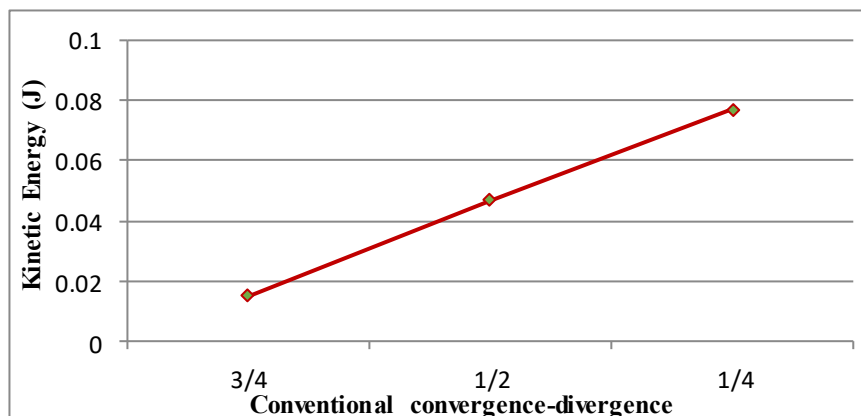
**Figure 5.** NACA nozzle velocity produced



**Figure. 6.** Convergence - divergence nozzle velocity produced



**Figure. 7.** NACA nozzle kinetic energy produced



**Figure. 8.** Convergence-divergence kinetic energy produced

Figure 7 and 8 illustrate kinetic energy captured by respective nozzle. The potential of NACA nozzle in capturing kinetic energy in slow fluid stream is enlighten as it harnessed more energy than conventional convergence-divergence nozzle. Maximum kinetic energy produced by conventional convergence-divergence is only 0.08 J at  $\frac{1}{4}$  diameter ratio while NACA 0012 is producing about 0.06 J even it is at the lowest among NACA profile.

Main factor that contribute to very significant gapping in velocity and kinetic energy relies on nozzle edge shapes. Besides of adequate diameter ratio that increase the velocity, nozzle edge profiles also have vital role which lead to reduction of turbulence flow. Even though inlet velocity of water is low which the flow is in laminar regime, the acceleration of flow across the nozzle profile caused disturbance in fluid flowing. Small fluctuations in the flow is sufficient enough to cause high frictional losses lead to high pressure drop [6]. In addition, it is found from this study curved nozzle profile is favourable in improving flow patterns as it relieves in delaying turbulence flow.

## 5. Conclusion

An experiment to investigate effect of nozzle profile to the flow velocity and potential kinetic energy in microscale channel were conducted in this study. By utilizing NACA profiles geometry and conventional convergence-divergence as nozzles, it indicated a significant finding on flow velocity and kinetic energy produced. This study revealed reduction of diameter ratio caused in accelerating the fluid flow but further reduction of contraction lead to frictional loss due to flow fluctuations. Furthermore, nozzles with NACA based profile enhanced flow characteristics by delaying turbulence therefore improve flow velocity and amount of kinetic energy.

## Acknowledgments

The authors gratefully to acknowledge Universiti Malaysia Perlis for providing fund via Short Term Grant (STG) 9001-00524.

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