ANSYS Water-Wind Flow Simulation to Study Pressure Generated Under Various Conditions to Generate Electricity Using Piezoelectric Cells

Rhitankar Saha Roy,*
School of Mechanical, Aerospace and Automotive Engineering,
Coventry University, UK
**Rhitankar123@gmail.com*

Lim Chong Lye, Lim Chin Guan
School of Engineering and Technology, PSB Academy, Singapore

Nor Mariah Adam
Faculty of Engineering, Universiti Putra Malaysia,
43400 UPM Serdang, Selangor, Malaysia

ABSTRACT

Currently there is a demand for clean renewable sources of energy. Very few developments have been done to harvest energy from natural phenomenon such as rain drops. The objective of this paper is to identify the pressure that can be developed from rain drops hitting the surface of a piezoelectric cell and the respective voltage that can be generated from it. This paper presents a model that has been developed to harvest the kinetic energy of rain using piezoelectric devices. The roof of the model was kept at 45° and subjected to load test and water pressure test to simulate conditions of a rainy weather and the test data were recorded. ANSYS analysis has also been performed with the fluid velocity being set at 20 m/s, 30 m/s, 40 m/s and 50 m/s which strikes the roof of a building kept at 0°, 45° and 60°. The analytical results were compared to the model experimental results for validating the process. Experimental results from the prototype recorded that a maximum of 18.7 Volts of electrical energy can be generated. This study proves that the harvesting small energy from rain is significant as a secondary source of green energy that could compliment to the green energy system.

Keywords: *piezoelectric, ANSYS, electricity, generator, wind-water*

ISSN 1823-5514, eISSN2550-164X

Received for review: 2019-09-20
Accepted for publication: 2020-07-09
Published: 2020-10-15

Introduction

With the global population increase the world consumption of energy has also risen. Research by Roper [1] has shown that an average human being in the future will use 12 kW/ person to live. This amounts to 2900 x 10^{15} BTU per year [1]. The research showed that at that level of energy depletion, fossil fuels will be completely depleted by the year 2300.

With the depletion of fossil fuels and non-renewable sources of energy, human beings have to heavily rely on renewable energy that can harvest electricity. The European Union adjusted its targets such that in 2023 major countries will try to increase use of renewable sources of energy to 32%. The Government of India plans to raise its target to 227 GW by 2027. Hawaii, USA aims to reach 70% energy independence by 2030 out of which 40% will be from renewable sources of energy [2].

Scientists have over the time developed electricity from renewable sources of energy. Some of the popular sources are solar energy, wind energy, tidal energy and geothermal energy. However, there are very few methods in which energy from falling rain can be utilised to generate electricity. There is even fewer research associated with utilising piezoelectric materials to develop solutions for low power supply devices [3].

Piezoelectric effect allows materials to convert mechanical energy to electrical energy and vice versa. The stimuli for piezoelectric materials can be human walking, wind, tide, wave, rain, etc [4].

Studies have been performed ot harvest energy from vibrating shoe-mounted piezoelectric cantilevers. Energy production from drops of rain striking a piezoelectric material in a cantilever configuration has also been shown in [5], [6], [7]. Research has shown the generation of voltage on the electrodes of a peizoelectric transducers subjected to rainfall [8].

A detailed study of harvesting of kinetic energy of raindrops by Perera et al. [4] has shown that during heavy thunderstorms, rain drops of size 5 mm can reach terminal velocity up to 9.09 m/s and has immense pressure. During heavy stratiform rain, the number of raindrops per 1 second on 1 m^2. A single large droplet can weigh upto 6.55 x 10^{-5} kg and the force generated per droplet is 5.95 x 10^{-4} N [9]. Guigon et al. [10] was able to conclude in their studies that energy can be harnessed during the impact of a raindrop.

Nayan et al. [11] was successfully able to show that the mechanical energy of raindrops can be harnessed by piezoelectric sensors to generate an average of 1 volt for each pressure. Using more piezolelectric sensors in series connection provides more supply to the load [12].

These researches showed that the use of piezoelectric transducers is a viable method to create electricity. This paper further focuses on the study of pressure generated from rain and wind which can be applied on piezoelectric cells and applications of it on a rooftop model.

Method and Analysis

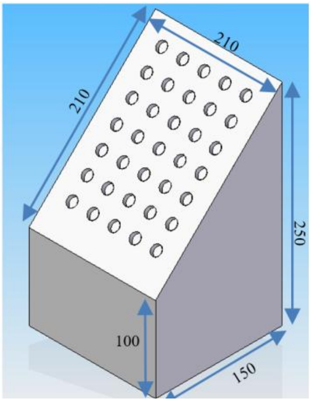
It has been assumed in this project that the fluid is hitting the surface of the roof top from one particular side only. This paper does not explore the effect when the fluid hits the surface from multiple sides at the same time. The impact of raindrop is considered to be perfectly inelastic. So, it is important to consider effect of splashing, rebound, partial rebound and spreading of rainwater. The effect of two-raindrop impact has been neglected. Moreover, it has been assumed that there will be no dissipation of energy in the form of heat or sound.

For the analytical experiments the roof top model was first designed using SolidWorks. The roof element is measured at 210 x 210 x 500 cm. Three models were designed for the experiment with the angle of the roof positioned in 0°, 45° and 60° as shown in Figure 1.

Figure 1: Angular view of rooftop model at 0°, 45° and 60°.

The models were then transferred in ANSYS to perform Fluid Flow (CFD) simulations. Both wind and rain (water) were used as fluids for the simulations. The fluid speed was set at 20 m/s, 30 m/s, 40 m/s and 50 m/s. The pressure contours recordings were then taken and recorded.

The prototype model was built keeping in mind that the main input on the piezoelectric cells was the force exerted by the raindrops and hence, the model was kept as basic as possible by discarding any external components that maybe present in traditional rooftops. Keeping the *SolidWorks* design intact, an element of the roof was taken into consideration. The rooftop is a square of 210 x 210 cm. The side panels are cut at 45° with outlet edge at 250 cm and inlet edge at 100 cm. The distance between the inlet and outlet is at 150 cm. Figure 2 shows the prototype model and the fabricated prototype.



(a) Prototype model


(b) Fabricated prototype

Figure 2. Prototype model as designed in ANSYS and the designed prototype.

When the raindrop strikes a piezoelectric cell surface, the pressure applied gets distributed and provides less shearing which results in lesser voltage distribution. As a result, for the prototype wood stacks or cork-stacks have been placed so that the pressure applied gets concentrated on the piezo transducers causing maximum potential difference.

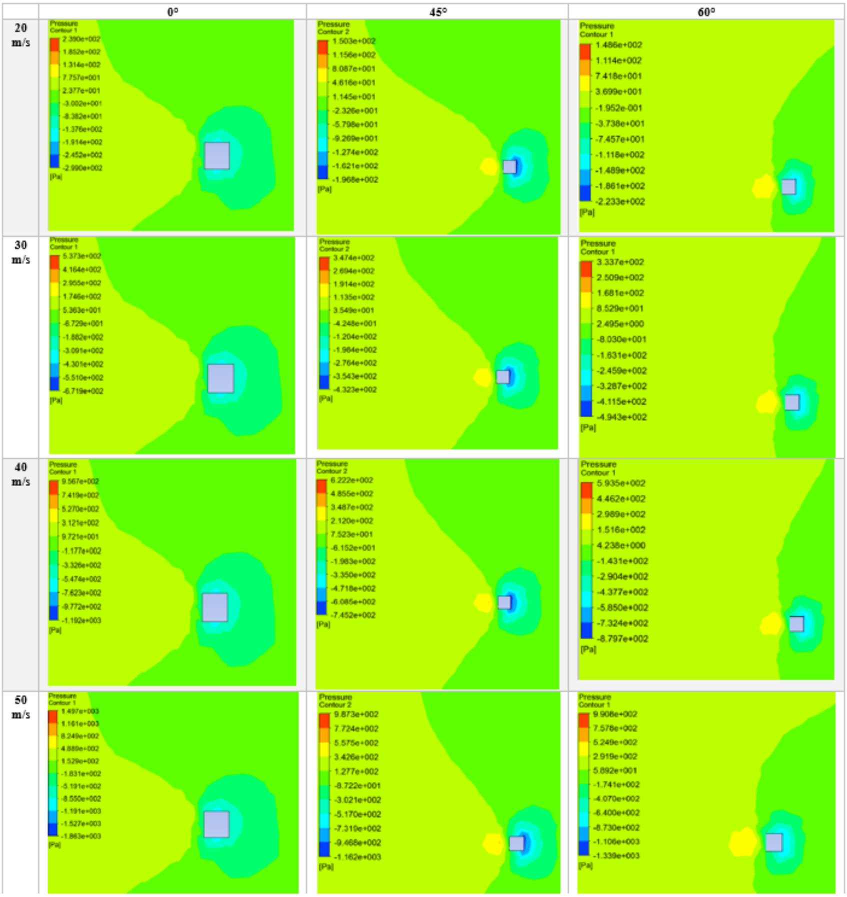
The piezoelectric cells are arranged in series-parallel connection. Higher the internal resistance of a cell, lower is its current flowing capacity. The cells are connected in parallel to reduce total resistance to a minimum. Using a series parallel connection improves both voltage and current generated.

The current developed by piezoelelectric transducers is alternating in nature which cannot be utilised to provide supply to the LED lights. However, of the current is passed through a rectifier the alternating current cab be converted to direct curentwhich can be further stored in a battery. A rectifier was hence developed using diodes and capacitor to convert AC to DC.

Results and Discussion

Having set up the ANSYS model, the pressure contour resulting from the fluid motion hitting the rooftop at various angles has been recorded in Table 1.

Table 1: ANSYS pressure contour results



The simulation in Table 1 shows that with an increase in the rooftop inclination angle, the effect of impact by the rain is less. This is shown by the pressure developed at the moment of impact is decreasing with increase in inclination angle. The pressure at the time of impact and has been used to develop the corresponding voltage that can be developed from it as shown in Table 2.

The piezoelectric material used for this experiment is a 7BB-20-3. It is made of brass with a plate diameter size of 20 mm, electrode diameter size of 12 mm, element diameter size of 14 mm and thickness of 0.22 mm.

Having found the pressure values, the following equation was then used to identify the voltage that can be generated from the piezoelectric cells in disc form and force being distributed over the thickness.

$$V = (g_{33}Fh)/(\pi r^2) \quad (1)$$

where,
V = Static Voltage
g_{33} = Piezoelectric constant
F = Force acting per unit area
h = thickness of disc measured as 0.22 mm.
r = radius of electrode size disc measured as 0.006 mm.
The piezo electric constant in this case is 26.5 x 10^{-3} Vm/N

Table 2: Voltage Calculations from ANSYS Simulation

Roof angle	Fluid flow speed (m/s)	Max pressure developed before hitting (Pa)	Voltage generated per cell (V)
0°	20	77.0	3.96
	30	175.0	9.02
	40	312.0	16.08
	50	489.0	25.21
45°	20	46.2	2.38
	30	113.5	5.85
	40	212.0	10.93
	50	343.0	17.68
60°	20	36.9	1.90
	30	85.3	4.40
	40	151.6	7.81
	50	291.9	15.05

In all rooftop inclination angles, it can be seen that with an increase in fluid velocity, more voltage is generated. This shows a direct collaboration with voltage developed with respect to pressure generated and fluid velocity during impact with the rooftop element. The comparison is further explored in Figure 3.

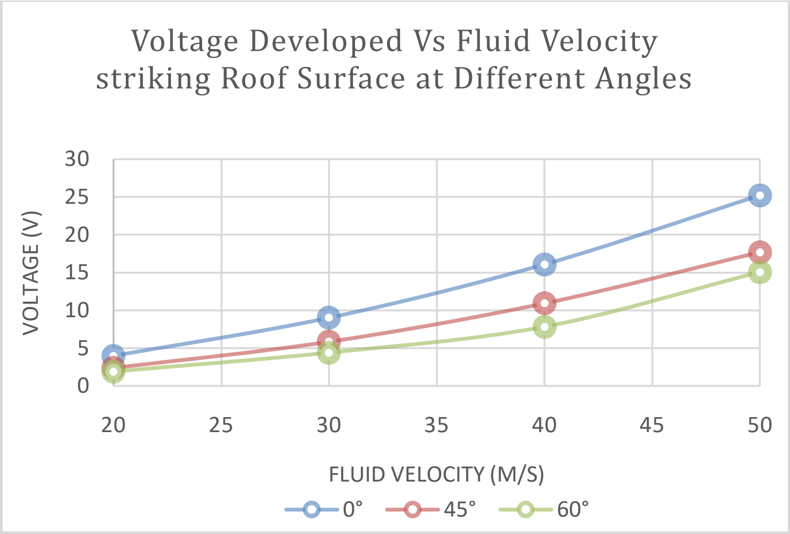


Figure 3: Voltage Vs fluid velocity.

Prototype testing

The piezoelectric cells were subjected to impact forces using an impact hammer. The force applied was measured using a load cell which gave an accurate value of the force striking the piezoelectric surface. The voltage developed was measured using a voltagemeter. The results have been shown in Table 3.

Table 3: Load experiment results

Force Applied (N)	Voltage Developed (V)
46.5	2.50
115	6.20
220	11.35
350	18.70

For a second experiment, a shower head hose was used to replicate the pressure the roof might face at high weather conditions. The protype was able to light up the LED lights perfectly. The voltage generated was between 2V to 15V as shown in Table 4. The level of water speed was changed through the five different levels of water pressure that can be set in the shower head as shown in Figure 4 [13].

Figure 4: 5 Different levels of water pressure [12].

Table 4: Shower head hose results

Level of Speed of water	Voltage Developed (V)
Level 1 – Drip Mode	2.20
Level 2 – Pulse Mode	5.40
Level 3 – Pulse and Spray	9.05
Level 4 – Spray Mode	13.93
Level 5 – Rain Pattern	14.73

The test showed that the ANSYS results correlated with the results obtained from the experiments performed on the prototype. At 45° of roof angle, the voltage generation was compared to values obtained from ANSYS at similar load pressure and the percent difference was very small for all cases. Table 5 compares the voltage results obtained from the ANSYS simulation and the force calculation results with the results obtained by performing experiments on the actual model. The percentage error was within 6% which is in good agreement.

Table 5: ANSYS simulation Vs modeltest results at 45°

Voltage result from ANSYS (V)	Voltage result from experiments (V)	Percentage difference (%)
2.38	2.50	4.8
5.8508	6.2	5.6
10.93	11.35	3.7
17.68	18.7	5.4

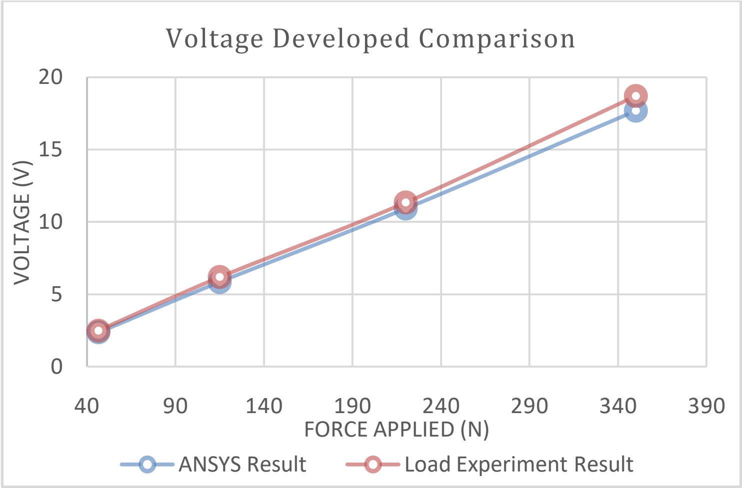


Figure 5: ANSYS vs model voltage developed comparison.

Conclusion

In conclusion, the present study has shown that rain water and wind can definitely act as potential sources to generate electricity by utilising the pressure developed from rain and wind striking roofs of buildings at various speeds.The experiments performed on the prototype model shows that piezoelectric models can be substantially used to generate electricity from pressure generated. The study can be used to design appropriate piezoelectric cells or piezoelectric harvesters to improve efficiency of generating electricity from falling rainfall and can be implemented in areas that receive moderate to heavy rainfall.

References

[1] L. D. Roper, "Future World Energy," *World Energy*, 2018. [Online]. Available: http://www.roperld.com/science/energyfuture.htm. [Accessed: 25-Dec-2018]

[2] World Health Organization, "Air Quality Guidelines Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide," *WHO*: Geneva, Switzerland, 2005.

[3] UNICEF, "Clear the Air for Children" 2016. [Online]. Available: www.unicef.org/publications/index_92957.html [Accessed: 22-May-2019]

[4] K. Perera, B. Sampath, V. Dassanayake and B. Hapuwatte, "Harvesting of kinetic energy of the raindrops," *Int J Math Comput. Phys Quantum Eng*, vol. 8, no. 2, pp. 325-330, 2014

[5] S. Kok, N. White and N. Harris, "Fabrication and characterization of free-standing thick-film piezoelectric cantilevers for energy harvesting," *Meas. Sci. Technol.*, vol. 20, 2009

[6] L. Moro and D. Benasciutti, "Harvested power and sensitivity analysis of vibrating shoe-mounted piezoelectric cantilevers," *Smart Mater. Struct*., vol. 19, 2010.

[7] L. Yabin and H. Sodano, "Optimal placement of piezoelectric material on a cantilever beam for maximum piezoelectric damping and power harvesting efficiency," *Smart Mater. Struct*., vol. 21, 2012.

[8] Q. Wang and N. Wu, "Optimal design of a piezoelectric coupled beam for power harvesting," *Smart Mater. Struct*., vol. 21, 2012

[9] R. Guigon, J.-J. Chaillout, T. Jager, and G. Despesse, "Harvesting raindrop energy: theory," *Smart Materials and Structures*, vol 17, no. 1, p. 015038, 2008.

[10] D. Vatansever, E and. Siores, T. Shah, "Alternative Resources for Renewable Energy: Piezoelectric and Photovoltaic Smart Structures," *Intech Open*, 2012.

[11] N. Nayan, M. Razak, A. Ali and S. Mazalan, "Development of Rain Harvester using Piezoelectric Sensor," *Jurnal Teknologi*.

[12] F. Viola, P. Romano, R. Miceli, G. Acciari and C. Spataro, "Piezoelectric model of rainfall energy harvester," *Viale delle Scienze*. 9th Edition, 2014.

[13] "Shower Head, CUCM High Pressure 5 Spray Settings with Drip Mode Adjustable Massage Spa Hand Held Shower head,

Chrome," *Amazon.co.uk: DIY & Tools*. [Online]. Available: https://www.amazon.co.uk/Shower-Head-CUCM-Pressure-Spray/dp/B07CQ1VQYN?ref_=ast_bbp_dp&th=1. [Accessed: 12-Mar-2019].