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Harnessing of Kinetic Energy of Raindrops

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Abstract: **Rain drops possesses kinetic energy as they descend gradually from the clouds. This kinetic energy can be utilized to generate electricity by use of piezoelectric materials. This paper illustrates the behavior and the procurable energy of the raindrops. A prototype to harness energy theoretical and experimentally study is also made. The material used is PVDF (Polyvinylidene Difluoride). The simulation of rainfall drop deflection is done by ANSYS.**

Keywords: **Raindrop, piezoelectricity, PVDF, terminal velocity, ANSYS.**

1. INTRODUCTION

Energy is essential for every nation to develop its integrity, infrastructure defense and citizen welfare. Energy demands increases as the years pass on. The energy consumption in India for the year of 2000 was 550TW-hr and in the year 2012 it was 1100TW-hr.this huge increase in energy demands increases stress on the resources of energy generation such as coal, nuclear, hydroelectricity etc. This resources are on the verge of getting extinct. The conventional fuel sources are exploited. Only 12% of the energy generation in India is obtained from renewable energy sources. It's the need of the hour to concentrate on renewable energy sources to avoid further environmental and energy crises.

Rainfall is the natural phenomenon in which rain drop possesses considerable kinetic energy which if utilized can be used to power household appliances or sensors which may reduce stress on conventional energy sources. We are trying to explore the probability of rain drop energy potential in India.

Several experiments are developed for raindrop energy harvesting [1, 2]. The basic concept behind the experiments is that, the rain drops from significant height due to gravity. Its velocity increases as it descends. It reaches a stage where th gravitational force and drag force is in equilibrium and it reaches a constant velocity called terminal velocity.

The mass of the rain drop and terminal velocity during impact gives kinetic energy to the piezoelectric membrane which, then converts the kinetic energy into piezoelectric energy. Basically, it's a vibrational energy. Rain drop size has a vital role to play and also the terminal velocity.

In India we have monsoon, during june –sept where solar energy is inefficient due to cloudy environments. The rainfall size in India varies from 1mm-5mm .thus june-sept period is very efficient in piezoelectricity generation.

In research study, we have performed numerical analysis using ANSYS structural analysis to determine the deformation in PVDF membrane. The analysis is done for various rain drop sizes for light strati form rain (LSR), moderate strati form rain (MSR) and heavy thunderstorm (HT)

2. REVIEW

2.1 Behaviour of Raindrop:

In order to determine the terminal velocity of the raindrop the raindrop is assumed to be spherical in shape.

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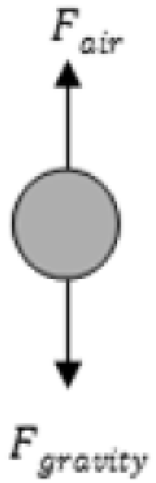

Fig.1. force acting on a spherical falling raindrop

Drag force on the raindrop acting vertically upwards

$$F_{air} = 0.5 * \rho_{air} * A * C * v^2 \quad (1)$$

The gravitational force on the raindrop

$$F_{gravity} = \left(\frac{4}{3}\right) * \pi * r^3 * \rho_{water} * g \quad (2)$$

Terminal velocity is achieved when the forces on the drop are balanced i.e a state of equilibrium is achieved.

$$F_{air} = F_{gravity}$$

$$v = \frac{\sqrt{\pi * d^3 * \rho_{water} * g}}{6 * \rho_{air} * A * C} \quad (3)$$

The above derived equation for terminal velocity is valid only, when raindrop is considered to be spherical. We find that the terminal velocity depends on the raindrop size i.e. diameter (d) and the drag coefficient(C).

TABLE: 1

Rain type	Drop size (mm)	Terminal velocity (Experimental) (m/s)
Light stratiform rain		
Small	0.5	2.06
Large	2.0	6.49
Moderate stratiform rain		
Small	1.0	4.03
Large	2.6	7.57
Heavy thundershower		
Small	1.2	4.64
Large	4.0	8.83

In actual sense, the shape of raindrop is constantly changing due to air resistance .The shape changing nature depends on the raindrop size. The drop sizes below 1mm are almost spherical whereas the size increases, the change in the shape increases accordingly.

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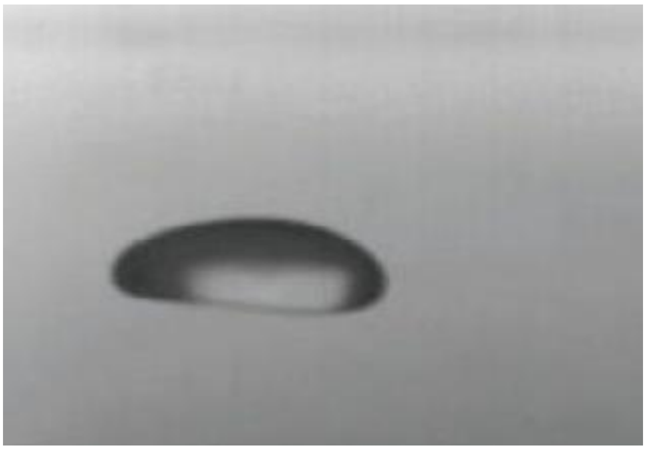

Fig.2. Water droplet in air resistance

Fig.3. change in shape of raindrop with diameter

2.2 Force Exerted By A Raindrop On Solid Surface:

According to research carried by guigon et el [1].in their analysis, they have used Mundo's criteria[5] and they have assumed that the impact of splash mode very close to inelastic impact of ball on plate.

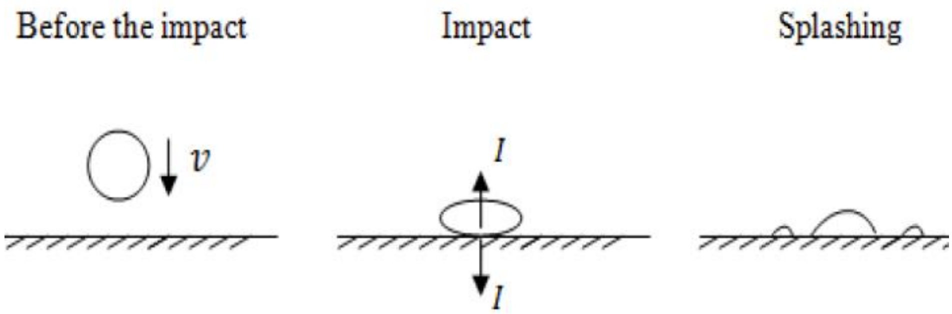

Fig.4. impact force on surface by raindrops

Newton's experimental law and the newton's second law can be applied in this scenario to obtain the momentum being transferred to the solid surface by impact of the raindrop.

Newton's law: *During the collision of elastic objects the ratio of relative velocities of the two objects determine in direction of common perpendicular constructed at point of impact after and before the impact is constant and opposite in direction. This constant is termed as dynamic elastic coefficient and varies from 0 to 1.*

$0 \leq e \leq 1$ (4)

e =0 for perfectly inelastic impacts

e=1 for perfectly elastic impacts

Applying newton's experimental law

$$e = \frac{u}{v} \quad (5)$$

Where u is velocity of raindrop after impact relative to solid surface along common perpendicular

V is velocity before impact relative to solid surface along the common perpendicular.

Since we have assumed the collision to be perfectly inelastic i.e. e = 0

And hence u = 0

Appling newton's second law on raindrop

$$I = mu - (-mv) = mv \quad (6)$$

According to newton's third law, the impulse on surface is equivalent to the impulse on raindrop.

Impact force is calculated by

$$F = \frac{I}{\delta t} = \frac{mv}{\delta t} \quad (7)$$

Δt is infinitesimally small, but in our study, we have considered definite time value of 1 second for determination of impact force on solid surface exerted by the raindrop.

TABLE: 2

Rain type	Drop size (mm)	Raindrop mass (kg)	Force calculation (N)
LSR			
Small	0.5	7.0 e-8	1.0 e-7
Large	2.0	4.19 e-6	2.72 e-5
MSR			
Small	1.0	5.2 e-7	2.1 e-6
Large	2.6	9.2 e-6	6.97 e-5
HT			
Small	1.2	9.0 e-7	4.2 e-6
Large	4.0	3.351 e-5	2.959 e-4

3. RAINDROP KINETIC ENERGY HARVESTING BY PIEZOELECTRIC MATERIAL

3.1 Piezoelctricity:

The phenomenon of generation of electric charge by a material when subjected to mechanical stress (direct effect), conversely generating mechanical deformation when electric field is applied is known as piezoelectricity.The material used for vibration energy harvesting plays a major role in efficiency and performance of the harvester. Usually the piezoelectric material used in many power harvesting applications is lead zirconate titanate (PZT).it is a piezoceramic known as PZT.

PZT is brittle in nature and thus has many limitations. The lead content even makes it toxic. Lee et al proved that piezoceramics (PZT) cannot withstand high frequency cyclic loading and are prone to fatigue crack growth.

Another common piezoelectric material is PVDF (Polyvinylidene Fluoride). It is piezoelectric polymer which is flexible as compared to PZT. The acceptable properties for PVDF are though, lower than compared to PZT but PVDF is quite flexible, lightweight, tough, and non-toxic (due to no lead content).

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TABLE: 3

	d_{31}, pm/V	k_{31}	Salient features
PVDF	28	0.12	Flexible, lightweight, low acoustic and mechanical impedance
PZT	175	0.34	Brittle, heavy, toxic

Coupling coefficient (k) is the ability of piezomaterial to exhibit charge on its surface due to deformation.

There are two types of coupling mode. In order to utilize the maximum charge generation on the poling surface selection of efficient coupling mode is priority viz. -31 mode and -33 mode.

31 mode is said to be obtained when the force is applied in direction perpendicular to poling direction.

A cantilever beam having poling surfaces on top and bottom is an example of -31 mode (uses in our harvester).

33 mode is said ,when the direction of force applied and poling direction are same as in the case of compression of a piezoelectric block that is poled on top and bottom.

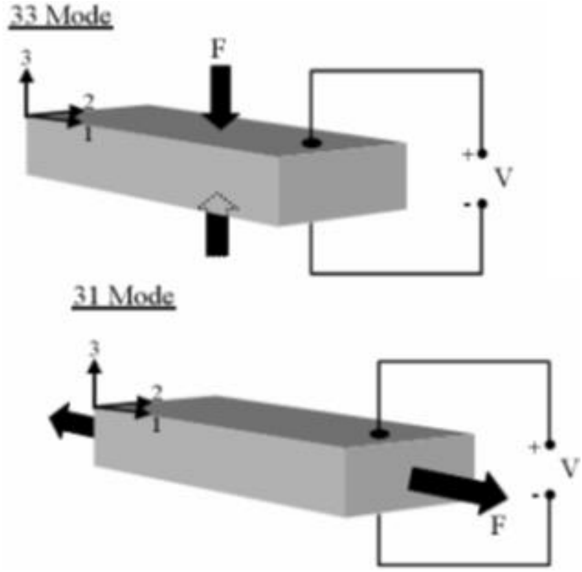

Fig.5. Modes of coupling of piezoelements

3.2 Energy From Raindrops:

Rain drops create an impact on the surface. This impact force can create vibrations on vibrating sensitive membrane. Piezoelectric materials if made and arranged in mechanical setup so as to act as a vibrating transducer can effectively harness this impact vibration energy.

Recent study by guigon et al [1 2] explains in detail with theoretical and experimental proof that scavenges the vibrating energy of raindrops. In our study we used PVDF material as it best suits the requirement in terms of flexibility, strength, and sensitivity to mechanical strain. The diagram fig 6. Shows the experimental setup for collection of vibration energy .several piezoelectric membrane are used to obtain the impact vibration without loss. The piezoelectric membrane used is arranged in a cantilever beam structure. The piezoelectric membrane has a dimension of 13mm * 25mm rectangular shape with thickness of 28µm. The material is flexible PVDF polymer with screen printed Ag- ink electrodes laminated to 0.125 mm polyester substrate and fitted with two crimped contacts. It contains a small mass placed at free end to improve its sensitivity for vibration sensing. As the piezo film is displaced from the mechanical neutral axis, bending creates a very high strain within the piezo polymer and therefore high voltages are generated.

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A diaphragm is placed which collects the raindrops and its edges are connected to the piezo elements. The piezo elements are set in -31 mode. As raindrop impact on the diaphragm, the vibration in diaphragm create bending in piezo elements creating voltages.

A proper regulating and amplifying summing circuit is later used to collect the voltages and store for later use.

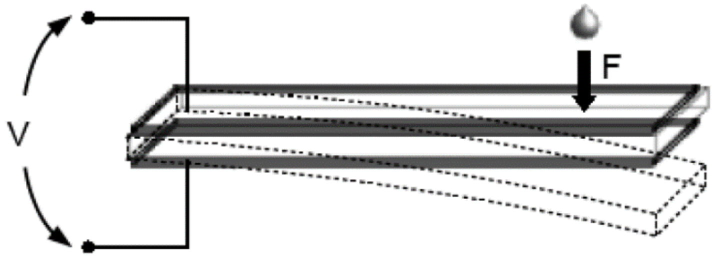

Fig.6. Schematic of cantilever beam deflection under impact force

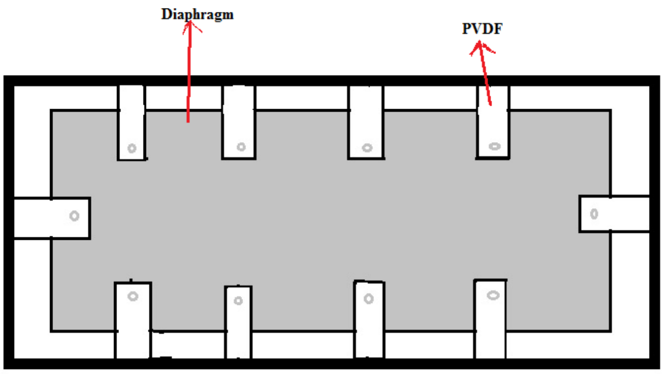

Fig.7. Experimental setup

The physical properties for PVDF material used –

TABLE: 4

MECHANICAL PROPERTIES OF PVDF

Property	Quantity	Units
Young's modulus(E)	3	10^9 N/m^2
Poisson ratio(μ)	0.34	[-]
Material density (ρ)	1780	kg/m^3

TABLE: 5

PIEZOELECTRIC PROPERTIES OF PVDF

Property	Quantity	Units
Strain coefficient(d_{31})	20	10^{-12} m/v
Piezoelectric constant(g_{31})	0.21	Vm /N
Coupling coefficient(k_{31})	0.11	[-]
Dielectric constant	12	$\varepsilon/\varepsilon_0$

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The total harvestable electrical energy in PVDF is formulated as

$$U = (k_{31})^2 * E * V * \frac{\epsilon^2}{2}$$

*k31 =coupling coefficient on -31 mode,

E=youngs modulus V=volume of film

$\boldsymbol{\epsilon}$=strain produced in film after deflection

The numerical analysis for strain in the PVDF membrane is obtained by structural analysis in ANSYS.

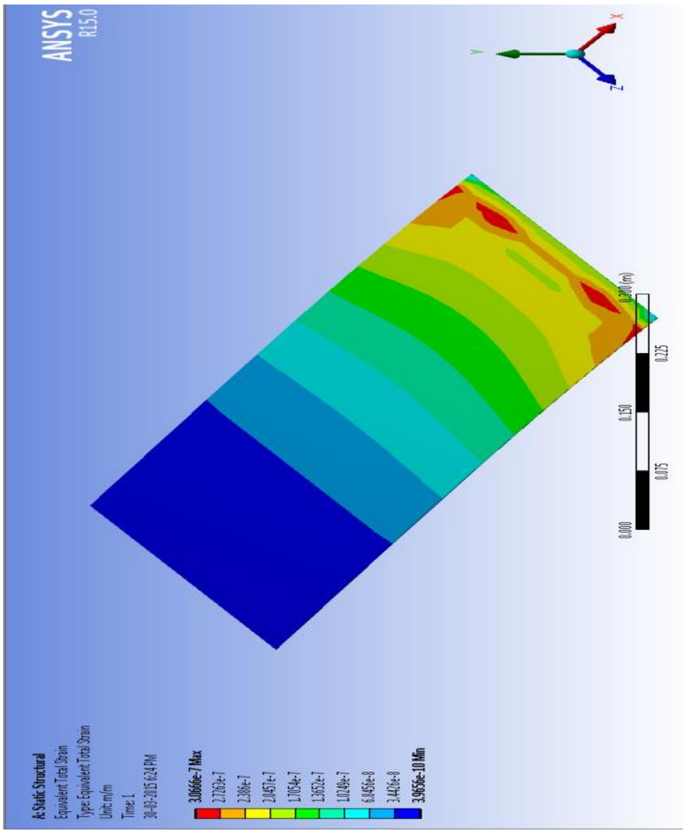

Fig.8. Strain in deformed PVDF element

The obtained strain and electrical is as below.

TABLE: 6

RAIN TYPE	FORCE(N)	STRAIN	HARVESTABLE ENERGY(J)
LSR			
small	1.0 e-7	4.673e-10	2.6608e-20
large	2.72e-5	2.8976e-5	1.0228e-10
MSR			
small	2.1e-6	9.8132e-9	1.17307e-17
large	6.97e-5	3.0666e-7	1.1455e-14
HT			
small	4.2e-6	1.9626e-8	4.67209e-17
large	2.959e-4	6.112e-6	4.55061e-12

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4. CONCLUSION

The numerical simulation of one rain drop impact can be analyzed but however the rain falls in random, thus accuracy for impact vibration is difficult to achieve. The kinetic energy is however wasted in other forms after impact as noise energy etc.

At this research level, the energy obtained is very minor enough to power the MEMS and small electrical sensors and appliances. In the next phase of research, we look at developing the harvesting technique for maximum energy generation.

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