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Innovative Hydroelectric System Model

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Abstract. This paper presents an Innovative Hydroelectric System Model. The proposed model is an example to maximize the capture of flow power. Bernoulli's equation is applied to calculate the power of flow work ($Power_{flow}$). Water pumps are used for flow generating. It is shown the calculation of power by using technical data of pump. From calculation, it is found that 16 of 37 pumps generate $Power_{flow}$ more than power written on pump motor which is hereby defined Flow Power Pump (FPP). This is a big chance to develop hydroelectric system by using this power. This is a paper work to support the theory for innovation development of generating electricity from hydro power. It is expected in the near future that hydroelectricity can run without the river.

Keywords: bernoulli's equation; hydroelectric; pump; innovation hydro power

1. Introduction

Presently, many researches are interested in electricity generating from renewable energy, for instance, Solar power, Wind power and Hydro power. Nevertheless, there is technology limitation of electricity generating. For example, solar cell can generate electricity at daytime only, wind turbine depends on the wind which is unstable and unpredictable, and hydroelectricity has to run of the river. [1]

Therefore, the current tends of research and development (R&D) focuses on equipment improvement with more efficiency [2-6], for instance, developing of solar tracking system and designing of various wind blades or for more power output. Consideration of technology limitation, however, it is found that removal of technology limitation hydro power seems to be most possible, i.e., making sunshine for all day and all night or making stable wind blow all time are harder than making water flow even far from the river.

Value of energy in Equilibrium is not zero. It is just static and stored in many forms such as potential energy or static pressure. Look at water in container, it has accumulated energy even net force equal zero. But if some forces act the water mass, it will cause flowing as well as energy in form of flow work

Water flow can be generated by containing water in the channel and then pushing water by pump. And this paper studies power of flow work by pump.

2. Literature Review

2.1. Flow work

Consideration of open system with mass flowing through the system, it is found that there should be some forces push the mass entering the boundary to be in or out of the system. This energy is called Flow Work, W_{flow}.

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Fig. 1. Flow of mass due to flow work

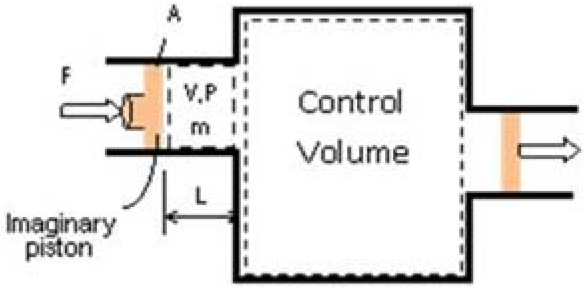
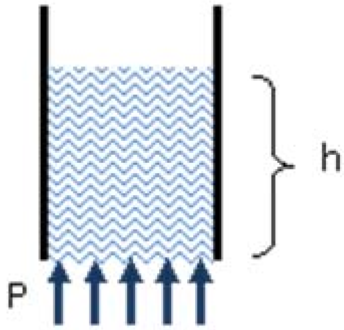


Fig. 2. Relation between Pressure (P) and head (h)



Refer to Fig. 1, fluid with Volume (V) is pushed to the system and there should be force to act for Length (L). That causes flow work which can be written as equation below;

$$W_{flow} = F.L \qquad kg.m^2/s^2 \qquad (1)$$

And from relation between Force and Pressure

$$F = P.A \qquad kg.m/s2 \qquad (2)$$

Accordingly $W_{flow} = P.A.L = P.V \qquad kg.m^2/s^2=Joule \qquad (3)$

Given P = Pressure (Pascal, N/m^2 , $kg/m.s^2$)
A = Area (Square meter , m^2)
L = Length (Meter , m)
V = Volume (Cubic meter , m^3)

If defining flow rate's unit of Q as m^3/s when finding power in 1 second, It can be applied that

$$Power_{flow} = P.Q \qquad kg.m^2/s^3 = J/s = Watt \qquad (4)$$

Equation (4) can be used for finding the power of flow work through the Control Volume by substituting the value of P and Q in the equation. Finding flow work from pump, Q value can be found from technical data of pump and P value from section 2.2.

2.2. Pump Pressure

Typically, the subject of Fluid Mechanic mentions energy value in form of head using unit of length for convenient usage. This head value can be converted to be in form of pressure, kinetic energy, or potential energy. Equation (5) shows converting head value to be pressure value [7].

$$P = 9810 . h . SG \qquad (5)$$

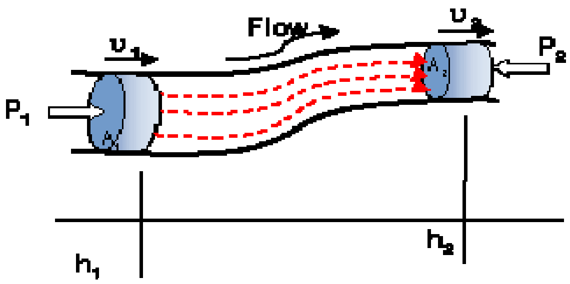
P = Pressure (Pascal, N/m^2 or $kg/m.s^2$)
h = head (meter , m)
SG = Specific Gravity, for fresh water equals to 1

Equation (5) is thereby from $P=\rho gh = 1000 \times 9.81 \times h = 9810.h$

Finding pump pressure is usually informed for head. Fig. 2 shows that if water can be lifted by pump for h meter, there should be pressure for ρgh or according to equation (5).

2.3. Bernoulli's Equation

Bernoulli's Equation is used for ideal flow and incompressible fluid with the steady flow[8].



P = Pressure (Pascal, N/m^2 or $kg/m.s^2$)
ρ = Water Density (kg/m^3)
υ = Flow Velocity (m/s)
h = head (m)

Fig. 3. Fluid in flow tube

From Bernoulli's Equation in pressure form;

$$P_1 + \frac{1}{2}\rho_1\upsilon_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho_2\upsilon_2^2 + \rho g h_2 = C_p \qquad (6)$$

Equation (6) is in pressure form. C_p is constant value of total pressure getting from gathering of pressure from flow, pressure from velocity and pressure from gravity potential. C_p value is equal at every point in the streamline. Multiple C_p with V (m^3) makes energy value in joule unit at any control volume for consideration. The unit of flow rate (Q) is m^3/s. Thus, multiple Q with equation (6) makes the result in Watt unit.

$$V(P_1 + \frac{1}{2}\rho_1\upsilon_1^2 + \rho g h_1) = V(P_2 + \frac{1}{2}\rho_2\upsilon_2^2 + \rho g h_2) = V.C_p = C_v \qquad \text{Joule} \qquad (7.1)$$

$$Q(P_1 + \frac{1}{2}\rho_1\upsilon_1^2 + \rho g h_1) = Q(P_2 + \frac{1}{2}\rho_2\upsilon_2^2 + \rho g h_2) = Q.C_p = C_q \qquad \text{Watt} \qquad (7.2)$$

C_v is constant value as an energy value from flowing water. It consists of work from pressure Q.V adding kinetic energy $V(\frac{1}{2}\rho\upsilon^2)$ and gravity potential energy $V(\rho g h)$.

Similarly, C_q is constant value as a power value from flowing water. It consists of work from pressure Q.P adding power from kinetic energy $Q(\frac{1}{2}\rho\upsilon^2)$ and power from gravity potential energy $Q(\rho g h)$.

3. Calculating the Power Value from Flow in The System

3.1. Set the system

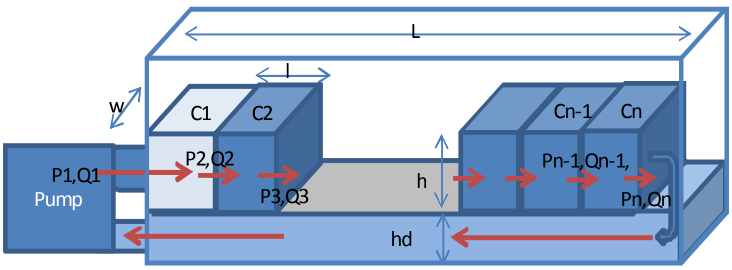


Fig. 4. The studied flow system

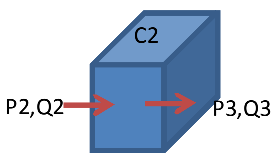


Fig. 5. Control volume (C2)

Refer to Fig. 4, this is 2-layer channel with submersible pump at the left side channel. The pump makes Pressure (P_1) and water flow into system with Flow rate (Q_1). Water in upper channel is at height 0.3 meters. Water flows from upper channel through the end and down to lower channel at height 0.2 meters. Then, it is pumped into the system again repeatedly.

3.2. Calculating the power value in the control volume C_1

Defining C_1 as Control Volume, flow work can be calculated as follows;

- Calculation *of Pressure value (P_1)*

P_1 is Pump Pressure which can be calculated by converting head into Pressure as equation 6.

Technical data shows that a submersible pump has Qmax=2000 l/h, Head=2 m and Power=32Watt. Calculate Pressure as follow.

$$P_1 = 9{,}810\ (2\ m)\ (1) = \mathbf{19{,}620}\ \text{Pascal}\ (N/m^2 \text{ or } kg/m.s^2) \quad (8)$$

- Calculation *of flow rate (Q)*

From above data, flow rate is Q= 2,000 liter per hour and can be converted to be cubic meter per second as $\frac{2{,}000 l/h}{1000 \times 3600} = 0.000555556\ m^3/s$

- Calculation *of constant power (C_1)*

As flow rate equals to Velocity multiplies with Area Q= υ. A or υ =Q/A, equation (7.2) can be substituted as follow;

$$C_1 = Q(P_1 + \tfrac{1}{2}\rho_1\upsilon_1^2 + \rho g h_1) \quad (9.1)$$

Substitute υ =Q/A in equation 9.1= $Q(P_1 + \tfrac{1}{2}\rho_1(Q/A)_1^2 + \rho g h_1)$ (9.2)

$$= QP_1 + \tfrac{1}{2}\rho_1(Q^3/A^2)_1 + Q\rho g h_1 \quad \text{Watt} \quad (9.3)$$

As height (h_1) is a half of upper channel adds height of lower channel (hd), thus h_1 is high from datum = hd+h/2 = 0.2m + (0.3/2)m = 0.35m, pump inlet has radius = 1 cm (=0.01m) and Area is $A = \pi r^2 = 22/7 \times 0.01^2 = 0.000314286\ m^2$

Calculate C_1 by substituting with value of variables in equation (9.2).

$$C_1 = 0.000555556\ (19{,}620 + \tfrac{1}{2} \times 1{,}000.(0.000555556 / 0.000314286)^2 + 1{,}000 \times 9.81 \times 0.35)$$

$$= 10.9 + 0.867967 + 1.9075 = \mathbf{13.67}\ \text{Watt}$$

3.3. Calculation of Power in control volume $C_2 \ldots C_n$

Continuous flow in the system also causes flow work in control volume C_2. The flow rate is equal at every point in channel according to law of mass conservation. And constant value of energy in control volume C_2 equals to constant value of energy $C_1 = C_2 = 13.67$ Watt but composition of constant value of energy C_2 is different from C_1.

- Calculation *of Pressure value (P_2)*

From equation (7.2);

$$C_1 = Q(P_1 + \tfrac{1}{2}\rho_1\upsilon_1^2 + \rho g h_1) = \boxed{Q(P_2 + \tfrac{1}{2}\rho_2\upsilon_2^2 + \rho g h_2) = 13.67}\ \text{Watt}$$

Reform; $P_2 = \frac{13.67}{Q} - \tfrac{1}{2}\rho_2\upsilon_2^2 - \rho g h_2$ Pascal, N/m^2 or $kg/m.s^2$

$$= \frac{13.67}{Q} - \tfrac{1}{2}\rho_2(Q/A)_2^2 - \rho g h_2 \quad kg/m.s^2$$

$$P_2 = \frac{13.67}{0.000555556} - \tfrac{1}{2} \times 1{,}000.(0.000555556 / 0.2\text{x}0.3)^2 - 1{,}000 \times 9.81 \times 0.35$$

$$= 21{,}182.3 \quad \text{Pascal } (kg/m.s^2)$$

- Calculation *of constant power (C_2)*
-

Calculate C_2 by substituting with value in equation (9.2).

$$C_2 = 0.000555556\ (21{,}182.3 + \tfrac{1}{2} \times 1{,}000.(0.000555556 / 0.2\text{x}0.3)^2 + 1{,}000 \times 9.81 \times 0.35)$$

$$= 11.767943 + 0.000024 + 1.9075 = \mathbf{13.67}\ \text{Watt}$$

Composition of power C_2 is different from C_1 in term of pressure and velocity but summation of power value is still 13.67 Watt.

- *3)* Calculation *of constant power (C_n)*

Similarly, power is equal at every control volume C_n. Thereby, when the system is in steady state, total power can be calculated as follow;

$$\sum C_{total} = C_1 + C_2 + \ldots + C_n$$

Supposing volume of pump inlet is very small comparing with volume of channel, thus, Volume of C_1 is 0.000555556 m^3, width of channel is 0.2 m. and height of water in upper channel is 0.3 m. From formula, Volume can be found from V = w.h.l

Accordingly, length of control volume C1; $l = \dfrac{0.000555556}{0.2 \times 0.3} = 0.009259259$ m

Similarly, length of control volume $C_2 \ldots C_n$; $l = 0.009259259$ m

If the length of upper channel is 2 m.;

C_1 has length 0.009259259 m. and power 13.67 Watt

C_1 to C_n has length 2 m. and power **2,952.72** Watt

When water enters into the system, it causes power. And when the system is in steady state, the system will have total power 2,952.72 W.; without consideration of loss from flow, increasing or decreasing heat into the system as well as any work input or output of the system.

4. Application of the Power$_{flow}$

Refer to 2.1, it is found that most power comes from pressure and flow rate of the pump, see equation (4) $Power_{flow} = P.Q$. Taking technical data of pump from market [9] to calculate $Power_{flow}$, excluded power from kinetic and gravity potential, it is found that some pumps have $Power_{flow}$, calculating from P and Q from technical data of pump, more than power written on pump motor. This paper calls a pump with more $Power_{flow}$ than power written on pump motor that **Flow Power Pump (FPP)** (see Fig.6 red line above 0%) and calls the less one that **Normal Pump**.

Table 1. Example Powerflow from some technical data of pump from market

	Model	Power input (hp)	Power input (watt)	flow (lit/min)	pump head (m)	Pressure (bar)	Power flow (Watt)	Gain (loss) (Watt)	Gain (loss) (%)
1	Example Submersible Pump	0.044	32.81	33.33	2	0.1962	10.90	-21.91	-67%
2	Centrifugal pump Model SAC130-2	0.5	372.85	90	23	2.2563	338.45	-34.40	-9%
3	Centrifugal pump Model SAC158-2	1	745.70	130	36	3.5316	765.18	19.48	3%
4	Centrifugal pump Model SAC180-2	1.5	1118.55	130	41	4.0221	871.46	-247.09	-22%
5	Centrifugal pump Model SAC190-2	2	1491.40	150	50	4.905	1226.25	-265.15	-18%
6	Centrifugal pump Model SAB-60	0.5	372.85	35	35	3.4335	200.29	-172.56	-46%
7	Centrifugal pump Model SAB-80	1	745.70	60	50	4.905	490.50	-255.20	-34%
8	Centrifugal pump Model SHK-60	0.5	372.85	35	35	3.4335	200.29	-172.56	-46%
9	Centrifugal pump Model SHK-80	1	745.70	60	50	4.905	490.50	-255.20	-34%
10	Centrifugal pump Model SHL-60	0.5	372.85	35	35	3.4335	200.29	-172.56	-46%
11	Centrifugal pump Model SHL-80	1	745.70	60	50	4.905	490.50	-255.20	-34%
12	Centrifugal pump Model SPK-60	0.5	372.85	35	35	3.4335	200.29	-172.56	-46%
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
33	Pump ESPA Model Multi 30-5M 1500 W	2	1491.40	175	65.4	6.41574	1871.26	379.86	25%
34	Pump ESPA Model Multi 30-6 2200 Watt	3	2237.10	175	82	8.0442	2346.23	109.13	5%
35	Pump ESPA Model Multi 40-6 3000 Watt	4	2982.80	350	69	6.7689	3948.53	965.73	32%

36	Submersible pump Aluminium Sawada Model AQ2-22550A (AUTO) diameter 2”	400	460	10	0.981	752.10	352.10	88%
37	Submersible pump Aluminium Sawada Model AQS2-22550A (AUTO) diameter 2”	400	320	13	1.2753	680.16	280.16	70%

Refer to table 1, $Power_{flow}$ from technical data of pump from market, it is found that 16 pumps are FPP and Power Gain is approximately 2.6% - 88%. The maximum Power Gain is Model 36, submersible pump Wasada AQ2-22550A (AUTO) inlet diameter 2” Power 400 watt, head 10 m. Calculating $Power_{flow}$ = 752.10 Watt, Power Gain = 352.10 Watt or 88%.

FPP is a recommended pump to make water flow as a source of hydro power for electricity generator because there is more $Power_{flow}$ than normal pump.

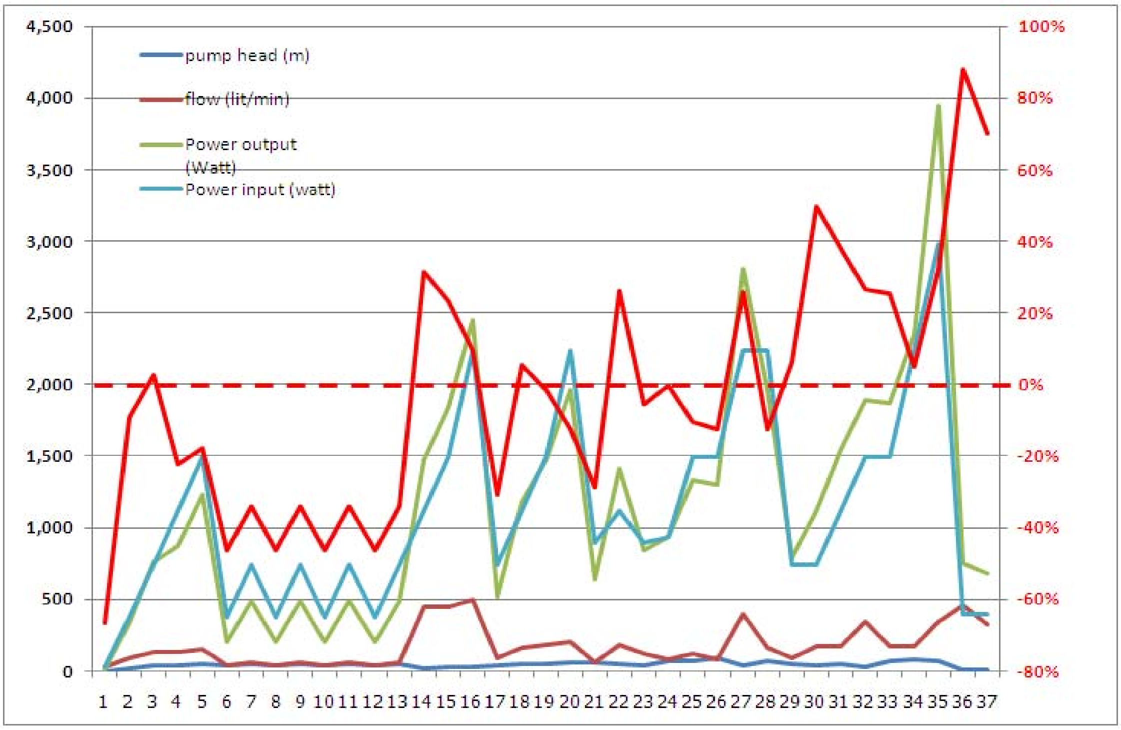


Fig. 6. Powerflow Calculating from P and Q from technical data of pump

5. Propose New Hydroelectric System Model

This section proposes an Innovative Hydroelectric System Model. The finding from above study suggests that Power value at each point is constant, i.e., although total power value in the system is up to 2,952.72 Watt (2.95 kW), power spread at many positions in the channel. So the power is not accumulated at the last point C_n only but spread during $C_1..C_n$. Thereby, all 2.95 kW energy cannot be captured to use from only a point at a second. In comparison, if there is 2,000 units of water in a container, punching only a hole can get water to use just 13 units per second not 2,000 units. Then applying the system by one turbine instalment at only point may not get all 2.95 kW power of the system. To make the turbine get more power, it may be done by increasing the number of turbines or designing blade to get more volume, etc. This is like punching more holes to get water from the container at a second as mentioned above. Briefly, new design of system is needed to capture the most volume of power.

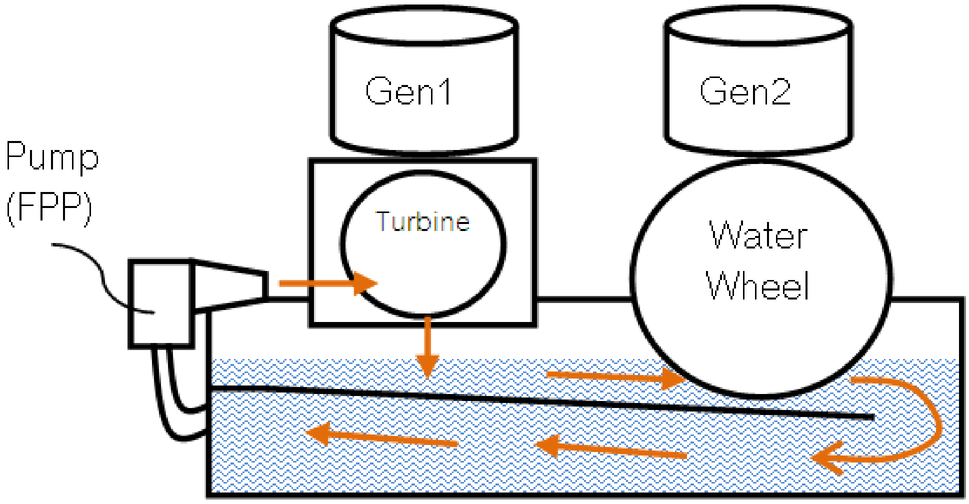


Fig.7. Innovative Hydroelectric System Model

Fig.7. presents an example of some power captures. The proposed new model generates flow from pump and capture power from 2 points. The first point is to capture the kinetic power from nozzle. And the second point is to capture the $Power_{flow}$ from water flow by pump suction. More points of power capture will take more power from the system. It is hoped that power output will be more than power used from pump.

Supposing a turbine efficiency is ($\eta_{turbine}$) 20-60% and a generator efficiency is ($\eta_{generator}$) 40-70%, so electrical power output can be generated approximately 236 ~ 826 Watt (2.95kW x 0.2 x 0.4 ~ 2.95kW x 0.6 x 0.7) which is more than 32 Watt power written on pump motor. There is power gain (net power/power in) = 6.38% ~ 24.81% ((236-32)/32 ~ (826-32)/32)). That sounds good.

6. Conclusion

Previously, Bernoulli's Equation is used for finding some variables needed to know in flowing system, for example, finding pressure and finding velocity at any point of flow tube. Nevertheless, this paper applies Bernoulli's Equation to find total power value. It starts by using Bernoulli's Equation in term of pressure (Pascal) and making it to be power (Watt) by multiplying pressure with flow rate (m^3/s). Flow rate is found easily from technical data of pump to calculate $Power_{flow}$ value. From some calculated technical data, it is found that $Power_{flow}$ from some pumps are more than from power written on pump motor which is called Flow Power Pump (FPP). And the pump is recommended to make water flow as a source of hydro power for electricity generator. Designing such hydroelectric system should be concerned that more points of power capture will take more power from the system. However, this proposed model needs more supporting experiments.

7. Acknowledgements

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