Coefficient of power of Indonesian traditional wind-pump blade model

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Abstract. Indonesia has wind energy potential as a renewable energy resource which is currently being developed intensively. Salt farmers have used it with wind-pump as part of the traditional salt-making process. They have the ability to manufacture, operate and maintain the Indonesian traditional wind-pump. The aim of the experiment was to find out characteristic of windmill of the traditional wind-pump. The characteristics was expressed with relation of coefficient of power (Cp) and the tip speed ratio (tsr). The ratio of the wind mill model was 1: 2.5. The wind mill model consisted of four blades and 80 cm diameter. The experiment was done in a wind tunnel with wind speed of 5 m/s. The adjustable shaft load was electric machine. In the experiment, the wind speed range was 5.7 up to 6.3 m/s and shaft speed was 42.3 up to 387.4 rpm. The experiment resulted minimum and maximum tsr and Cp were 0.295 up to 2.705 and 2.623 up to 11.073, respectively. The experiment found out relationship of Cp and tsr in an equation Cp = -3.248 tsr^2 + 12.29 tsr – 1.007. The equation showed that the traditional windmill model has maximum Cp of 10.62 at the tsr of 1.89.

1 Introduction

Climate changes was major challenge for sustainable development worldwide countries and many efforts to reduce the rate of CO_2 addition. In Indonesia, many renewable power generations were existed, such as wind power, solar power, hydro power and geothermal power for electricity. Wind energy was one of fasted growing of electricity generating technology [1] and Indonesia has wind energy resources which highly potential for development.

Indonesian salt farmer used solar thermal and wind energy as main energy resources throughout the salt making process. Salt farmer community at northern of Central Java and East Java Province used solar thermal energy for evaporation process and wind energy for entire of brain water circulation process by wind-pump equipment. The salt farmer utilized wind energy by using the wind-pump which consisted of wind-mill blades, crank-shaft, reciprocating pump and supporting structure. Entire of wind-pump components can be made,

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manufactured and repaired by the local salt farmer as a mechanism to reduce and save production cost.

For 2 up to 5 m/s wind speed, pumping head of 45 cm and crank-shaft arm length of 7.5 up to 10 cm, the wind-pump pumped the brain of sea water of 0.89 up to 1.31 litre/s [2]. The reciprocating pump was could replace with centrifugal pump. The centrifugal pump could be placed about 50 m from the wind mill [3]. For 2 up to 4.5 m/s wind speed, 50 m distance and pumping head of 45 cm, the wind-pump pumped the brain of sea water of 0.21 litre/s [4]. The power from windmill shaft to the 50 m length of centrifugal pump shaft was transmitted electrically [5].

Based on assessment of a wind pumping system with variation of wind velocity measured during field operation, the maximum value of Coefficient of power was 35% and maximum combined efficiencies of the components was 17% [6]. It was very difficult to find information of characteristics of Indonesian salt-farmer's traditional wind-pump. The characteristics of a wind mill was expressed by its coefficient of power and efficiency. The characteristic information of the traditional windmill was very important for its potential and express the local wisdom.

Characteristic of a wind mill was shown relation of coefficient of power and its tip speed ratio. It was difficult to get characteristic information of Indonesian traditional wind mill for salt farmers can produce and build his own wind mill and its pump systems. A traditional wind mill from northern Java Island was studied in the open atmosphere at southern of Yogyakarta [7]. Studied at the open air gave fluctuation and high variation data of wind speed. The wind speed was uncontrolled. The variation of the wind speed was 3.4 m/s up to 5.0 m/s and gave shaft speed up to 250 rpm. For four blades experiment was resulted maximum coefficient of power 10.2 at the tip speed ratio of 5.4.

Fig. 1. Traditional wind-pump of salt farmer**.**

This experiment investigated characteristic of a model of wind-mill of traditional wind-pump. The two main dimensionless parameters were tip speed ratio and coefficient of performance. The wind-mill was come from salt farmer of Babalan, Demak Region, Central Java Province. The actual blades diameter of the wind-mill was 2 meter or 200 cm, Figure 1. The ratio of the wind mill model was 1: 2.5.

2 Experiment methods

The experiment equipment consisted of a pairs of blades model (four blades), a shaft and an electric machine with a simple torque-meter. The equipment was installed in a wind tunnel. Dimension of wind tunnel was 120 cm, 120 cm and 240 cm of wide, height and length, respectively. The wind tunnel was attached at suction area of a 100 cm diameter blower driven by 5.5 kW motor. A 10kW electric controller was used to adjust motor speed for wind speed of 0 up to 8.5 m/s.

The blades model was made from boards, as the original material with 10 mm thickness and diameter was 80 cm or 800 mm (Figure 2). The shaft has 19 mm diameter and 40 cm length. The shaft was supported by two bearings and it was attached on simple rigid structure in a wind tunnel. A cross junction was attached on one side of the shaft for the blades installing to the shaft. A fixed coupling was attached on the other side of the shaft for shaft electric machines. On the shaft was installed two bearing that attached on a rigid structure. The electric machine was a 24 VDC 150 W magnetic motor and used for shaft load of the wind mill model. The shaft load was adjustable by load controller that connected to the electric machine. The cross junction of blades, the shaft and the electric machine was sat in-line axis and the axis was in-lined with wind tunnel and blower axis.

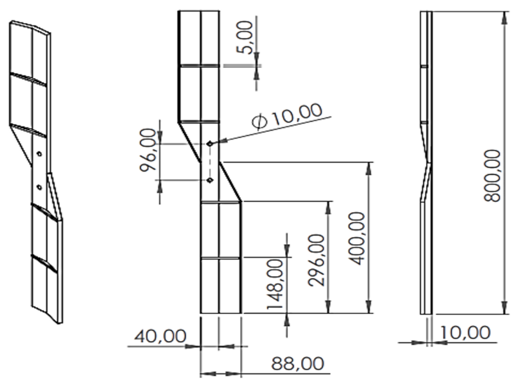

Fig. 2. Traditional dimension of the blade's model.

Coefficient of power (Cp) was ratio of power output and power input. The power input was wind power, $P_{in} = 0.5\,\rho\,A\,V^3$ and the power output was shaft power was $P_{out} = 2\;\pi\,\dot{n}\,F\,r$. The tip speed ratio ($tsr$) was ratio of blade tip speed and wind speed. V, A and ρ was wind speed, swept area and air density, respectively. V was measured by an anemometer. The wind speed at this experiment was adjusted about 6 m/s. A was calculated based on blade diameter (0.8 m) and was found A = 0.503 m^2. ρ was assumed 1.226 kg/m^3 as density of standard air. $\dot{n}$ was shaft speed in rps (revolution per second) and was measured by a tachometer. F was force acting on the tip of torque arm and was measured by weight-scale in kg. r was length of torque arm (18 cm).

Based on equations of P_{in} and P_{out} shaft speed, wind speed and torque arm force were the main parameters that must be obtained. Shaft load was adjusted during the experiment, there was 76 set data of wind speed, shaft speed and torque arm force.

3 Results and discussions

Based on the 76 sets data collected, the maximum, average and minimum wind speeds was 6.3, 6.0 and 5.7 m/s, respectively. For the shaft, the maximum, average and minimum shaft speeds was 387.5, 241.1 and 42.3 rpm, respectively. The shaft speeds were converted to rps (revolution per second) for further calculation. The maximum, average and minimum torque arm forces was 0.220, 0.143 and 0.065 kg, respectively.

Values of wind power input P_{in} were calculated based on parameter variation of wind speeds. Values of shaft power output P_{out} were calculated based on parameter variations both of shaft speeds and torque arm forces. Based on both of P_{in} and P_{out} was found Cp. Along with calculations of Cp was calculated blade tip speeds by parameter variations of shaft speeds and also was calculated the tsr. The relation of both parameter values of Cp and tsr was expressed in Figure 3.

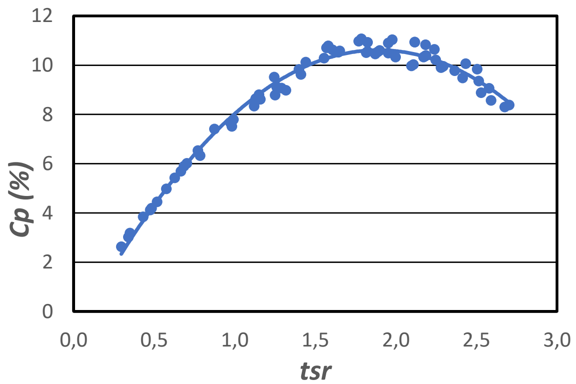

Fig. 3. Relationship of $\boldsymbol{Cp}$ and $\boldsymbol{tsr}$.

The minimum, maximum and average values of tsr during the experiment was 0.295, 2.705 and 1.596, respectively. The minimum, maximum and average values of Cp was 2.623, 11.073 and 8.810. Relationship of tsr and Cp was in the form of parabolic curve with the trend line of Cp = -3.248 tsr^2 + 12.29 tsr – 1.007 and R^2 = 0.9849.

The curve shape of the wind mill model was very similar with the curve shape of the four blades windmill without scaling. The maximum value of the wind mill model and wind mill without scaling was 11.073 and 10.2 [7]. The difference of the wind mill model and wind mill without scaling was the range of tsr. This difference was occurred of the load difference. The load of wind mill without scaling was generator electric machines and was resulted tsr range of 0.2 up to 5.4.

4 Conclusions

The experimental study of Indonesian traditional wind-pump blade model was successfully investigated and found out coefficient of power as one of characteristic parameter. The experiment resulted minimum and maximum tsr and Cp were 0.295 up to 2.705 and 2.623 up to 11.073, respectively. The experiment found out relationship of Cp and tsr in an equation of Cp = -3.248 tsr^2 + 12.29 tsr – 1.007 and R^2 = 0.9849. The equation showed that the traditional windmill model has maximum Cp of 10.62 at the tsr of 1.89.

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