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The performance and feasibility analysis of solar-powered screw pumps for the agricultural sector in Thailand

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Abstract

A solar water pumping system is an ideal alternative to electric water pumping system and it is useful for the agricultural sector in Thailand. In this study, the angle of the screw pump (θ), the solar cell panel, the motor speed (n) and the number of screws is varied. In the first part of the screw pump result, the volume flow rate and the mass flow rate ($\dot{m}$) are increased as the n and the number of screws increases. In the case of the low angle of the screw pump, the volume flow rate and the $\dot{m}$ are higher than in the case of the high angle of the screw pump. In the second part of the solar energy result, the solar cell panel is installed in the south-facing direction of Nakhon Nayok province in Thailand. The temperature of the solar panel surface follows a similar trend to the light intensity. The angle of the solar cell panel (α) is 15^o and 13:00 is the time that provides the maximum light intensity and temperature of the solar cell surface. In the last part of the performance analysis, the power and the efficiency of the motor are increased as, the n and the number of screws increase. In addition, the solar-powered screw pump is more feasible than the screw pump into electrical energy when used over long time periods.

Keywords: Screw pump, Solar Cell Panel, Angle of Inclination, Performance Analysis, Feasibility Analysis

1. Introduction

Energy has become a basic requirement for our everyday life and for the global economy. Due to the continuing growth of the world's population and increasing living standards worldwide, energy consumption globally is expected to jump significantly. An energy crisis is one of the issues which have imposed many changes in the development of various technologies around the world. The supply of energy resources to an economy is an energy crisis due to the development and population growth leading to a surge in the global demand for energy in recent years [1]. As global temperatures and energy demand rise simultaneously, renewable energy might possibly be used to replace the vast quantities of oil and gas [2]. A mechanical device is a mechanical structure that uses power to apply forces and control movement. It can be driven by natural resources, such as wind, water, oil, coal, natural gas, and sunlight [3]. A pump or water pump is one type of mechanical device; it is a device that moves fluids or sometimes slurries, by mechanical action, typically converted from electrical energy into hydraulic energy. The pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps [4]. The pumps operate by a reciprocation or rotary mechanism and consume energy to perform mechanical work moving the fluid. The mechanical pumps can be used in a wide range of applications such as in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas, or for operating cooling towers and other components of heating, ventilation, and air conditioning systems. In Thailand, the agriculture sectors comprise establishments primarily engaged in growing crops, raising animals, and harvesting fish and other animals from a farm, ranch, or their natural habitats. Nowadays, water pumps are widely used in the irrigation and agricultural development of Thailand [5]. There are several types of pumps such as centrifugal pumps, vacuum pumps, hydraulic pumps, peristaltic pumps, diaphragm pumps, rotodynamic pumps, and screw pumps, etc. [6]. A screw pump is a positive-displacement pump that uses one or several screws to move fluids or solids along the screw axis. In its simplest form, a single screw rotates in a cylindrical cavity, thereby moving the material along the screw's spindle [7]. The screw pump has several advantages such as the simple design, open structure, and slow rotation speed which make it a heavy-duty pump with minimal wear that operates for years without trouble. The screw pump can operate even when there is no water in the inlet. Therefore, it is not necessary to install the level control, and the efficiency (η) curve of the screw pump is flat on the top. Due to that efficiency characteristic, the screw pump even offers high efficiency when working at only 50% of its capacity. Because of the low rotational speed and large opening between the flights, screw pumps do not damage this biological flock. The screw pump requires very little maintenance and this type of pump is highly suitable for remote locations [8].

During the past decades, several researchers have conducted investigations in order to increase the performance of screw pumps [9-14]. Liu, et al [12] evaluated the performance of a multistage electrical submersible twin-screw pump (ESTSP) under different operating conditions. Mineral oil and water were selected as test liquids. The pump was tested with a maximum differential pressure of 1000 psi. The gas volumetric fraction (GVF) varied from 0% to 85%. The flow rate capacity and the volumetric efficiency were investigated in this research. An existing model to predict the leakage flow of the single-stage twin-screw pump was improved by extending the application for the multistage pumps. The model showed good agreement with experimental data under various operating conditions. Yongkang, et al [13] analyzed the theoretical model to determine the factors affecting the performance of the piezoelectric screw pump. The geometrical parameters of the piezoelectric vibrator were optimized by the finite element method, and a prototype was made for testing. The results showed that under the driving frequency of 13.8 kHz, the maximum backpressure was 6.70 kPa and the maximum flow was 750 μL /rpm. Moreover, this novel piezoelectric screw pump was simple in structure and could maintain the state of the liquid circuit by self-locking when power was off and had higher reliability. Renewable energy is useful form of energy that is collected from renewable resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat [15]. Solar power is energy from the sun that is converted into electrical energy. Solar energy is the cleanest and most abundant renewable energy source available. Thailand has some rich solar resources but the capacity for storage and the knowledge of solar power technology is lacking [16]. Some researchers have seriously studied solar-powered pumps [17-27]. Chandel, et al [22] presented a comprehensive literature review of solar pumping technology, and evaluating the economic viability, identifying research gaps and impediments to the widespread propagation of solar water pumping systems and technology. Solar water pumping was found to be economically viable in comparison to electricity or diesel-based systems for irrigation and water supplies in rural, urban, and remote regions. In addition, the evolution of solar-power pumps from the past until now is shown in Table 1. Some groups of researchers have investigated other applications such as drinking water, rural water supply, irrigation, and power generation in order to increase the performance of water pumps, heat pumps, and screw pumps.

Table 1 Evolution of solar-power pumps.

Country	Application	Type of pump	Methodology	References
England	Drinking water	Water pump	Theoretical analysis	Short et al. [17]
China	Rural water supply	Heat pump	Experimental analysis	Jie et al. [18]
USA	Irrigation	Water pump	Experimental analysis	Kala et al. [19]
Japan	Rural water supply	Heat pump	Theoretical analysis	Shin'ya et al. [20]
Jordan	Irrigation	Water pump	Experimental analysis	Aligah [21]
India	Irrigation	Water pump	Literature review	Chandel et al. [22]
India	Irrigation	Water pump	Literature review	Vimal and Vilas [23]
China	Agricultural, industrial, and domestic sectors	Water pump	Literature review	Guiqiang et al. [24]
China	Steam generation	Tandem screw expander	Experimental analysis	Pengcheng et al. [25]
Italy	Solar electricity generation	Screw expander	Mathematical model	Paolo et al. [26]
Iran	Power generation	Archimedes Screw Turbine	Numerical analysis	Shalverdi [27]

From the above literature review, solar-power pumps were studied in several countries via several methodologies. In the regions of Asia, pumps are used for agricultural, industrial, and domestic sectors. But the solar-powered screw pump was not comprehensively investigated for its performance and feasibility. For several reasons, the screw pump is investigated for a new design and this screw pump can be developed for the agricultural sector in Thailand. All parameters are evaluated for the performance and the feasibility of the solar-powered screw pump. In the future, solar energy for screw pumps is a promising alternative energy source instead of using conventional electricity-based pumping systems. The Ministry of Energy of the Kingdom of Thailand has announced ten urgent action plans for 2020 to support living expenses for Thais, maintain the country's energy security, and become a regional leader in the sector. Renewable power plant businesses have for many years been promoted by Thailand's government to reduce the heavy reliance on fossil fuels in Thailand and to reduce the environmental impact. Solar energy is obtained from the sun's radiation and it can be converted to energy. In Thailand, solar energy is freely available and it is now possible to harness even more of the solar energy that is continuously available to us due to advances in technology. The advantage of solar energy is that it has the least negative impact on the environment compared to any other energy source. It does not produce greenhouse gases and does not pollute the water. It allows an increase in energy self-reliance, because as long as there is sunshine, solar energy can be deployed anywhere. This is particularly useful for remote regions with no access to any other source of electricity, while another key factor is that of job creation. A large part of the cost associated with solar systems comes from the installation of the panels. This contributes to local job creation. Using solar systems boosts the economy and positively affects the local community.

2. Materials and methods

2.1 Governing equations

The continuity and Navier-Stokes equations which are coupled with the Coulomb force equation are considered from Equation (1) and (2), respectively. They are expressed by:

$$\nabla \cdot \vec{u} = 0, \tag{1}$$

$$\rho\left[\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla)\vec{u}\right] = -\nabla \vec{P} + \mu \nabla^2 \vec{u} + \vec{F}, \tag{2}$$

where $\bar{u}$ is waterflow velocity (m/s), ρ is density of water (kg/m^3), μ is viscosity of water (kg/ms), t is time (s), P is pressure (N/m^2) and F is motor speed (N).

The optimum design of the screw pump demands an extensive study of the performance criteria. The screw pump is always a trade-off between the theoretical optimum and the cost needed to create it. There are two sets of design aspects, which affect the overall geometry of the device, in the form of internal and external parameters. The screw pump consists of a cylindrical shaft, around which a blade or rubber strap is stuck to the cylindrical shaft. The geometry of the screw pump is like a conventional screw. The screw pump is rotated, which traps water between two consecutive flights. This body of water is called a 'bucket' and is raised along the trough as the screw turns. The water flows into the bottom of the screw, causing it to turn. The hydrostatic pressure the water exerts on the bucket surfaces causes the screw to turn, lowering the bucket in the process [28]. The screw pump design is based on the principles of mechanical engineering and the geometrical details of the screw pump are shown in Figure 1 [29]. In this case, d is the inner diameter of the blade (m), L is the length of the screw (m), and θ.

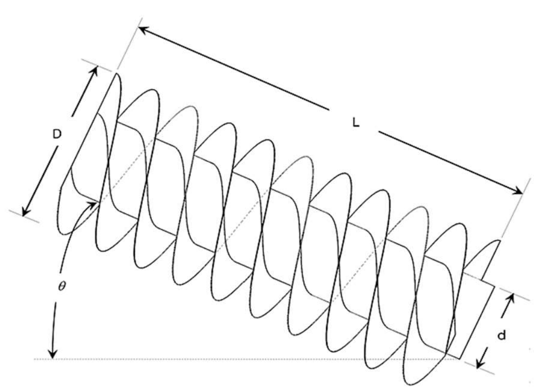

Figure 1 The geometrical details of the screw pump [29].

Each device must have the optimum values for the internal parameters for the specific external condition set. The volume flow rate (Q) and the $\dot{m}$ are calculated from Equation (3) and Equation (4), respectively. The maximum power (P_{max}) is calculated from Equation (5),

$$Q = knD^3, \tag{3}$$

$$\dot{m} = \rho Q, \tag{4}$$

$$P_{max} = \rho g h Q, \tag{5}$$

where k is the geometrical coefficient, n is motor speed (rpm), D is the outer diameter of the blade (m), g is gravity (m/s^2) and h is the head of the water source (m).

The torque $(\bar{T})$ and the mechanical power (P) of the motor are considered from Equation (6) and (7), respectively. T oɪ the screw pump (η) is calculated from Equation (8). These are expressed as:

$$\bar{T} = \bar{F} \times \bar{r} \tag{6}$$

$$P = \bar{T}\bar{\omega} = \bar{T}\left(\frac{2\pi n}{60}\right), \tag{7}$$

$$\eta = \frac{P}{P_{max}}, \tag{8}$$

where r is the radius (m) and ω is the angular velocity (s^{-1}).

The solar cell system consists of the solar cell panel, battery, solar charge controller, and power inverter. The solar energy can be converted to the direct circuit by the solar cell panels, and the energy is stored in the battery. A charge controller keeps the batteries from overcharging. It regulates the voltage and current coming from the solar panels going to the battery. A power inverter is a power electronic device or circuitry that changes direct current (DC) to alternating current (AC). The energy of the solar cell panel (E) should be measured from Equation (9) [30].

$$E = A \times r \times H \times PR, \tag{9}$$

where A is the solar panel area (m^2), r is the solar cell panel yield (kWh), H is light intensity (Lux) and PR is the performance ratio.

From the feasibility analysis, the payback period (PP) is a key consideration affecting policy-making because total investment is the fundamental force driving capital investment decisions. All else being equal, shorter payback periods are preferable to longer payback periods [31,32]. The payback period in capital budgeting refers to the period of time required to recoup the funds expended in investment and is calculated from Equation (10). Net return (Y_i) is the amount received from a company's activities, and is composed of an initial investment (TS), operating cost, maintenance cost, and electricity rate, after costs have been taken away as calculated from Equation (11). They are expressed by:

$$PP = \frac{TS}{Y_i}, \tag{10}$$

and

$$\text{Net return} = (\text{Initial investment} + \text{Operating cost} + \text{Maintenance cost} + \text{Electricity rate}) - \text{Return} \tag{11}$$

2.2 Description of the experimental setup

Schematic diagrams of the solar-powered screw pump for the experimental study are shown in Figure 2 and it is designed using solid modeling computer-aided design. For experimental setup, the screw pump is fixed to the cylindrical shaft. The rubber strap of the screws is rotated to the cylindrical shaft and the cylindrical shaft is connected with the motor. The outer diameter and the inner diameter of the cylindrical shaft are 0.17 m x 0.03 m, respectively. The diameter of the rubber strap is 0.03 m (3 cm) and the length of the cylindrical shaft is 2.00 m. The belt-pulley-shaft systems are connected with the motor in order to reduce, the n. The water flow is rotated from the bottom to the top. The water inlet receives water from the reservoir and the water outlet transfers water to the bucket. Schematic free body diagrams of the solar-powered screw pump are shown in Figure 2. The side view and the top view are shown in Figure 2 (A) and (B), respectively. The prototype of the screw pump (Figure 2) for the experimental study is created using solid modeling computer-aided design (Figure 2 C). The single screw (N = 1) and the multiple screw (N = 2 - 4) scenarios are shown in Figures 3 (A) and (B), respectively. The experimental setup of the solar-powered screw pump is shown in Figure 4. All of the components for the solar-powered screw pump are installed in Figure 4 (A). The main two parts of the component are the screw pump and the solar cell panel. For the experimental setup, the solar-powered screw pump is tested at the Chulachomklao Royal Military Academy, Nakhon Nayok province, Thailand. For Figure 4 (B), the screw pump is composed of the screw pump prototype (the rubber strap of the screws is rotated to the cylindrical shaft and the cylindrical shaft is connected with the motor), and the belt-pulley-shaft systems are connected with the motor. The bottom side of the screw pump is connected with the reservoir in order to receive the water inlet. At the top side, the water outlet is transferred to the bucket and the screw pump prototype is installed inside of the building. The solar cell panel is installed in a south-facing direction and is installed on the outside of the building. All parameters are evaluated by the Q and the $\dot{m}$. In this angle of inclination, the θ is varied from 15 – 75° and the α is varied from 0 – 90°, as shown in Figure 2 (A). The n is varied from 0 – 100 rpm and the number of screws (N) is varied from 1 – 4. For the max value, the number of N is increased by the rubber strap until filling the slots, and the slots are fully filled when the number of N is 4 (N = 4). In addition, the initial investment and payback period are compared with the solar cell energy and electrical energy. Finally, the performance and the feasibility of the solar-powered screw pump are calculated in order to create the suitable design for the agricultural sector in Thailand.

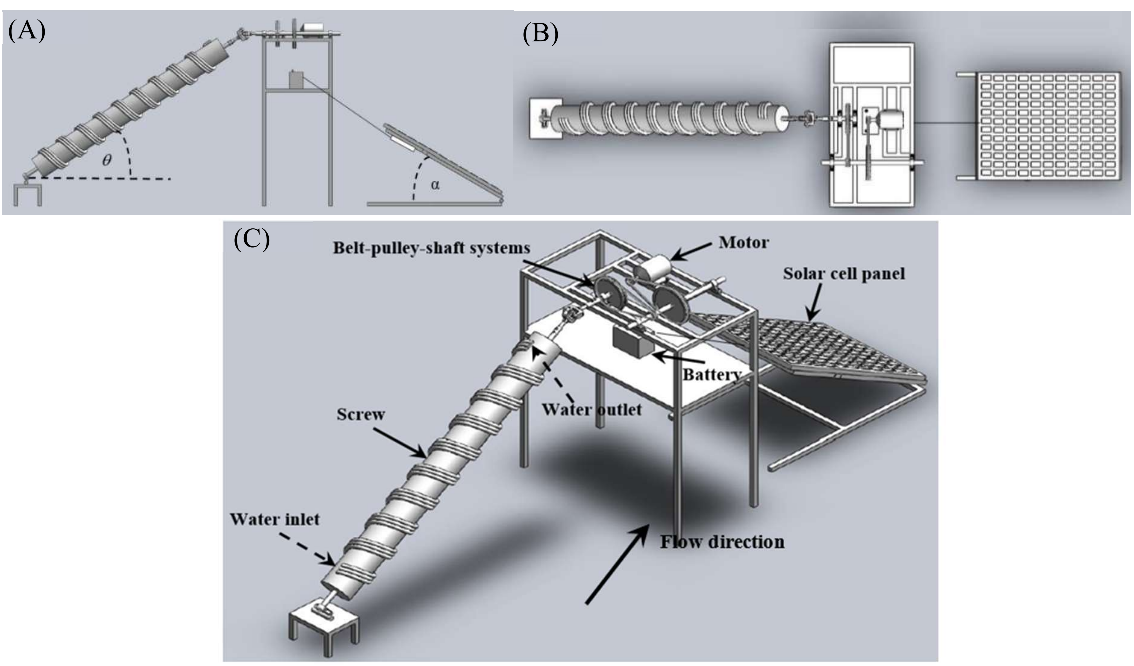

Figure 2 Schematic free body diagrams of the solar-powered screw pump: (A) size view; (B) top view, and (C) an oblique view.

(A) (B)

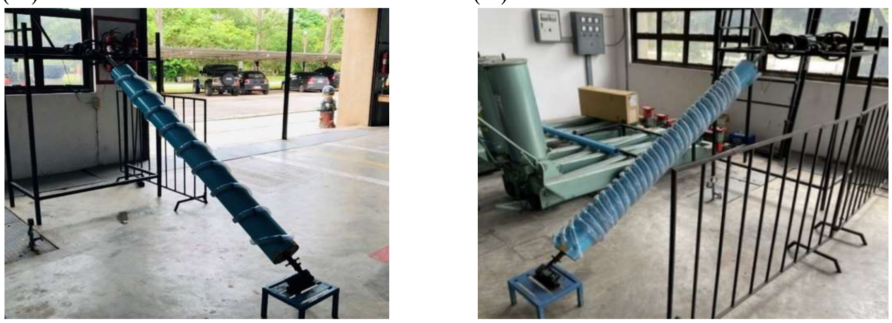

Figure 3 Screw pump prototype: (A) single screw; (B) multiple screws.

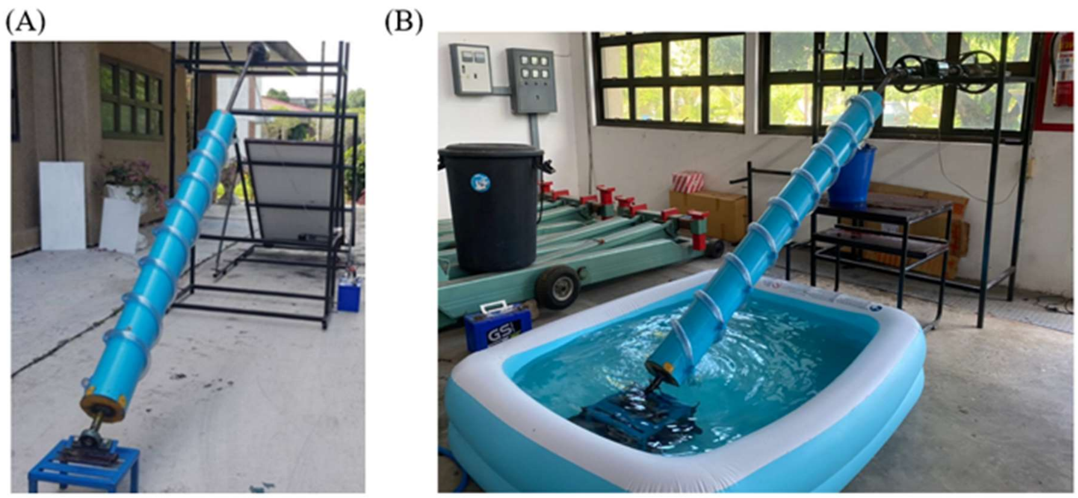

Figure 4 Experimental setup of the solar-powered screw pump: (A) screw pump with solar cell panel; (B) experimental setup.

3. Results and discussion

In this experimental setup, the solar-powered screw pump based on the difference between angles of inclination is tested at the Chulachomklao Royal Military Academy, Nakhon Nayok province, Thailand. From the control condition, the temperature and the relative humidity are controlled at 35 – 40 °C and 66 - 68%, respectively. The θ and the angle of the solar cell panel (α) are compared. Furthermore, the n and the number of N are evaluated by the Q and the $\dot{m}$. Finally, the performance of the power (P) and the efficiency (η) of the screw pump are analyzed and the feasibility analysis of the solar-powered screw pump is evaluated in terms of the initial investment and payback period.

3.1 Experimental study of the screw pump

In order to compare the effect of Q and the $\dot{m}$, (n) is varied from 0 – 100 rpm by increments of 10 rpm, θ is varied from 15 - 75° by increments of 15°, and N is varied from 1 - 4 by increments of 1. The n and θ are compared with the volume flow rate, as shown in Figure 5. From Figure 5 (A) (N = 1), the volume flow rate is slightly increased with the increasing and it is slightly different from the θ increasing. From Figure 5 (B) (N = 2), the volume flow rate is gradually increased with motor speed increasing but the volume flow rate is fairly obviously increased with the the θ decreasing. From Figure 5 (C) (N = 3), the volume flow rate is clearly increased with motor speed increasing and the θ decreasing. It can be seen that the volume flow rate of N = 3 is clearly higher than in the case of N = 2. At various angles of the screw pump, the volume flow rate is notably increased as the n increases, as shown in Figure 5 (D) (N = 4). The volume flow rate is increased with the n increasing and the volume flow rate in the case of a low angle of the screw pump is higher than in the case of a high angle of the screw pump. It can be seen that the volume flow rate is proportional to the the n and it can also be written as Q $\propto$ n.

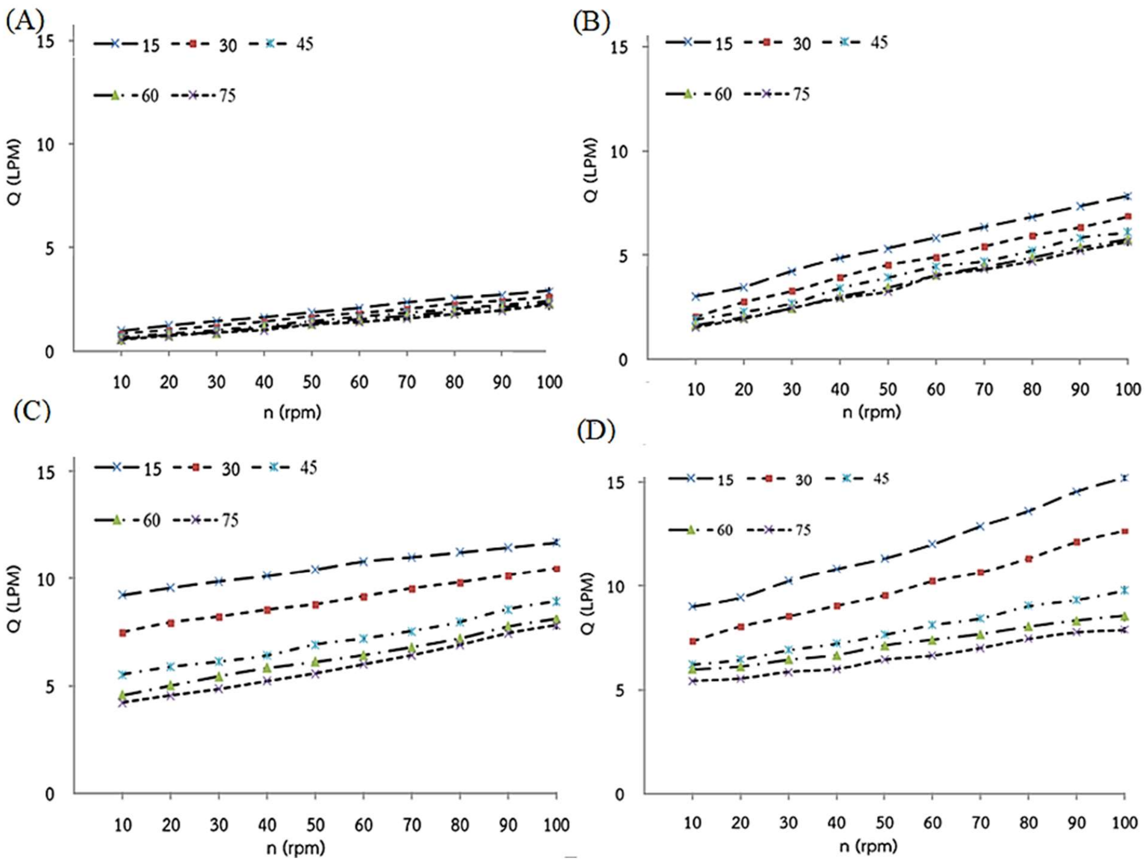

Figure 5 Comparison between the volume flow rate and the n for various angles of the screw pump and numbers of screws: (A) N = 1; (B) N = 2; (C) N = 3; (D) N = 4.

The θ and the n are compared with the volume flow rate, as shown in Figure 6. The volume flow rate is increased as the n increases. From Figure 6 (A) (N = 1), the volume flow rate is slightly decreased with the θ increasing and there is little difference as the n increases. From Figure 6 (B) (N = 2), the volume flow rate is fairly obviously decreased with increasing the θ. In the case of the high number of screws (N = 3 - 4), the volume flow rate is very obviously decreased with increasing the θ, as shown in Figure 6 (C- D). So, the volume flow rate is inversely proportional to the θ and it can also be written as $Q \propto 1/\theta$. In all cases, the variable straight line for the volume flow rate is decreased with the θ increasing. Figure 7 shows the n is varied from 10 – 100 rpm by increments of 30 rpm. From Figure 7 (A), the volume flow rate in the case of the low number of screws (N = 1 - 2) is clearly lower than in the case of the high number of screws (N = 3 - 4). The volume flow rate in the case of the low number of screws (N = 1) is clearly the lowest but it can gradually increase as the the n increases, as shown in Figure 7 (B - D). At the low number of screws (N = 1), the volume flow rate appears low in all cases. It can be seen that the single screw (N = 1) is not a suitable design for this mechanical device due to this design not yet achieving the highest performance. For implementation, the single screw pump is not feasible for economic viability.

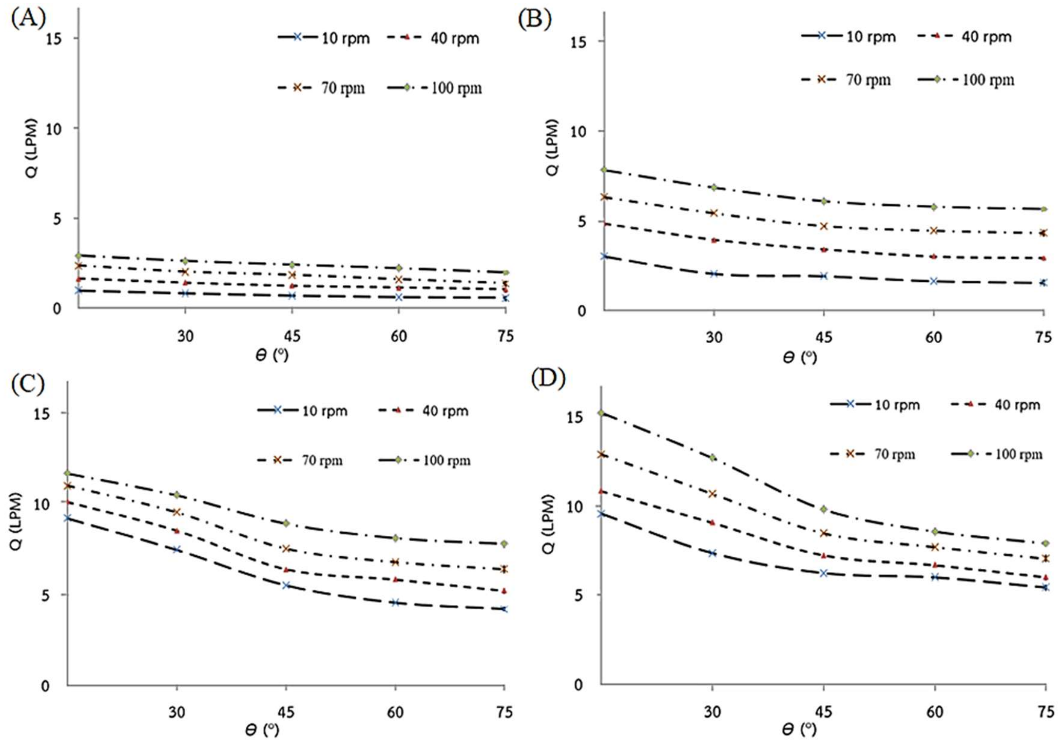

Figure 6 Comparison between the volume flow rate and the θ at various motor speeds and numbers of screws: (A) N = 1; (B) N = 2; (C) N = 3; (D) N = 4.

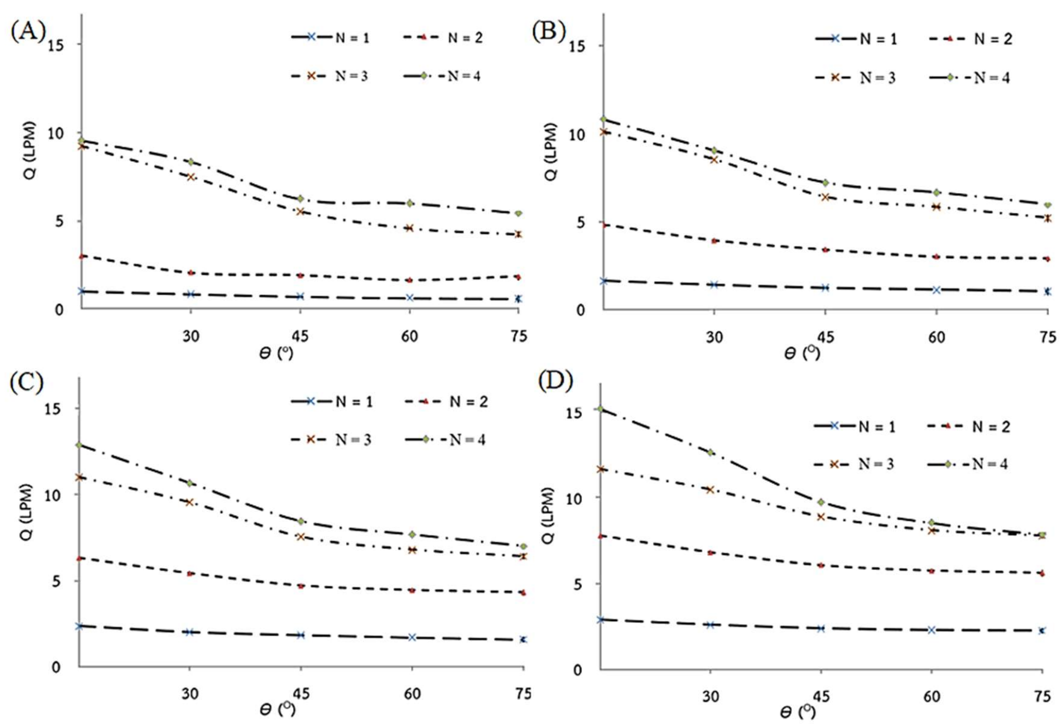

Figure 7 Comparison between the volume flow rate and the θ for various numbers of screws and motor speeds: (A) n = 10 rpm; (B) n = 40 rpm; (C) n = 70 rpm; (D) n = 100 rpm.

The volume flow rate and the $\dot{m}$ are compared in Figure 8 and the θ is fixed at 45°. The number of screws is varied from 1 to 4 by increments of 1. In all cases, the volume flow rate shows a similar trend to the $\dot{m}$, and the volume flow rate and the $\dot{m}$ are increased with the number of screws increasing. From Figure 8 (A) (low motor speed (n = 10 rpm)), the volume flow rate and the $\dot{m}$ in the case of a low number of screws (N = 1 - 2) are lower than in the case of a high number of screws (N = 3 - 4). From Figure 8 (B - C) (medium motor speed (n = 40 and 70 rpm)), the volume flow rate and the $\dot{m}$ are increased as the number of screws increases. A steep line graph is shown in Figure 8 (D) (high motor speed (n = 100 rpm)). The volume flow rate and the $\dot{m}$ are clearly increased as the number of screws increases. At medium to high motor speeds, the volume flow rate and the $\dot{m}$ are shown in the straight line graph. The volume flow rate and the $\dot{m}$ are clearly increased in the case of maximum values (number of screws (N = 4) and maximum motor speed (n = 100 rpm)). This represents the highest performance of the design and this design is therefore the most suitable design and offers feasible economic viability.

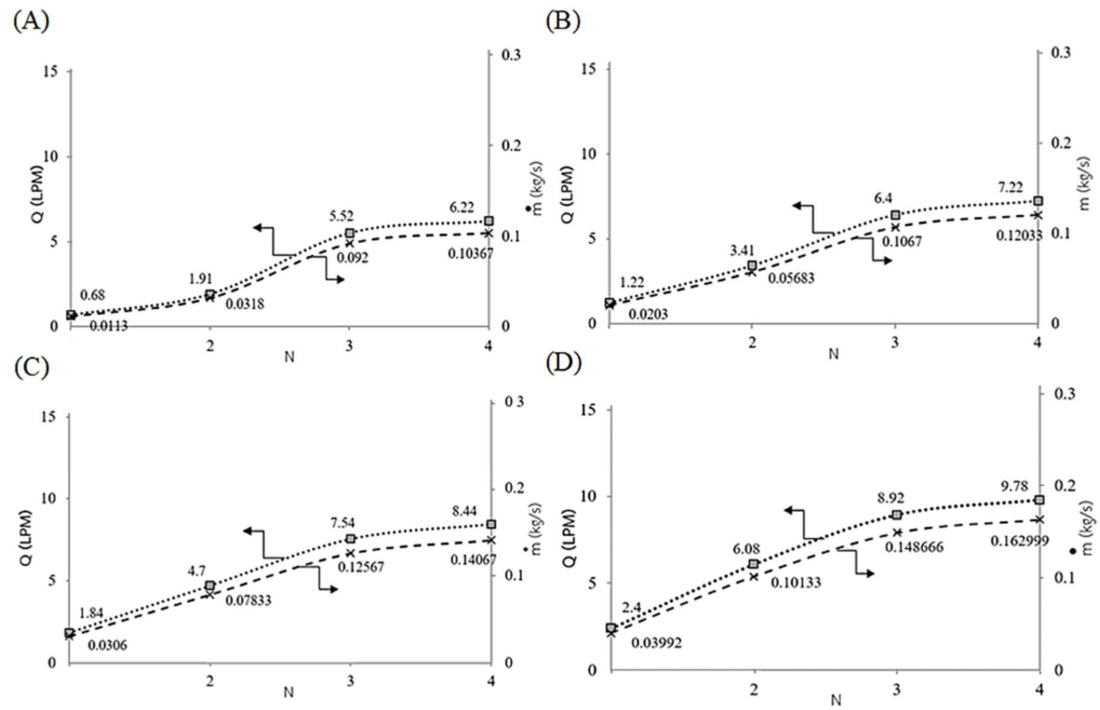

Figure 8 Comparison between the volume flow rate and the $\dot{m}$ for various numbers of screws and motor speeds when the θ is 45°: (A) n = 10 rpm; (B) n = 40 rpm; (C) n = 70 rpm; (D) n = 100 rpm.

3.2 Experimental study of solar energy

In order to compare the effect of the light intensity and the temperature of the solar panel surface, the α is varied from 0 – 90° by increments of 15°. The solar cell panel is installed in a south-facing direction in Nakhon Nayok province in Thailand. According to the collected data, the results are collected from 09:00 in the morning to 15:00 in the afternoon at intervals of 1 h. The experimental period is tested under very similar weather conditions. The collected data are investigated three times and an average score is used for these experimental results. In the case of unfavorable weather conditions, the experimental results are abandoned. The data of the light intensity and the temperature of the solar panel surface are measured by lux meter and digital temperature indicator. The nine points are measured at the face of the solar cell panel and the average score is used for collecting the data. The solar panel angle of the solar system is different depending on the location of the experimental setup. Solar panels give the highest energy output when they are directly facing the sun. The sun moves across the sky and will be low or high depending on the time of day. For this reason, the ideal angle is never fixed to get the most sun reaching the panel throughout the day. In this study, solar tracking is assumed, and an optimal tilt angle is calculated in order to study the performance of the solar-powered screw pump. The light intensity is a measure of the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle, based on the luminosity function. The light intensity and the time at various angles of the solar cell panel are compared, as shown in Figure 9. From 09:00 to 13:00, the light intensity increases as time progresses, and then it is gradually decreased when the time progresses from 13:00 to 15:00. Photovoltaic glass can collect induced temperature by absorbing sunlight. It can generate significant electrical power and the amount of electrical energy will depend on the performance of the collector. The light intensity from 09:00 to 13:00 rapidly increases, and after 13:00 is gradually decreased because the solar energy collection is performed at the surface of the solar cell panel. It can be seen that most modules use wafer-based crystalline silicon cells or thin-film cells. In addition, the light intensity in the case of α = 15° is the maximum value and in the case of α = 90° it is the lowest value. The temperature of the solar cell surface shows a similar trend to the light intensity, as shown in Figure 10. From 09:00 to 13:00, the temperature of the solar cell surface is increased as time progresses, and it is gradually decreased when the time progresses from 13:00 to 15:00. In addition, the temperature of the solar panel surface is affected by the light intensity. The light intensity and the temperature of the solar cell surface are compared at various angles of the solar cell panel, as shown in Figure 11. The light intensity and the temperature of the solar cell surface in the case of α = 15° provide the maximum value. So α = 15° is the suitable design for the solar cell panel installation at Nakhon Nayok province in Thailand.

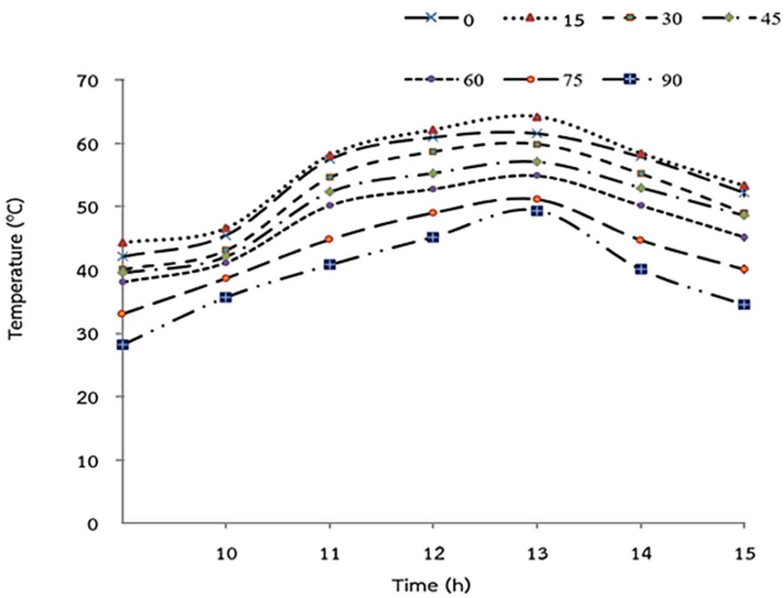

Figure 9 Comparison between the light intensity and the time at various angles of the solar cell panel.

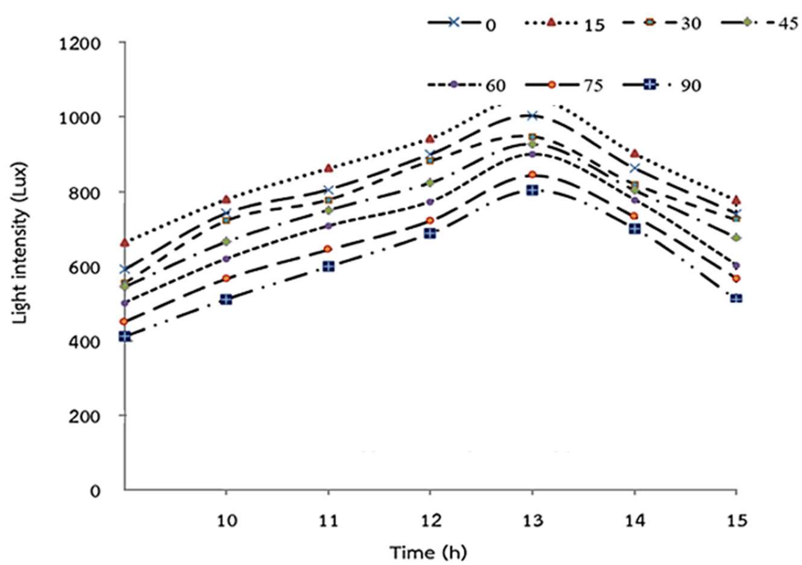

Figure 10 Comparison between the temperature of the solar cell surface and the time at various angles of the solar cell panel.

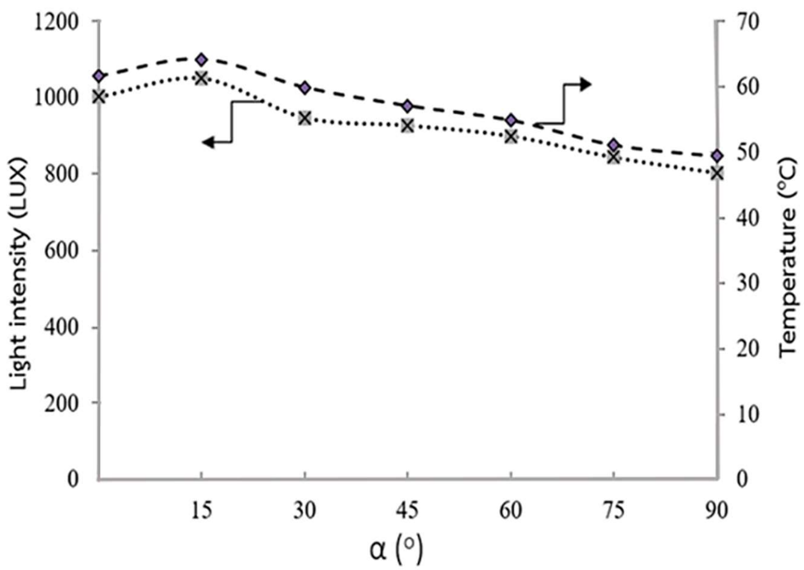

Figure 11 Comparison between the light intensity and the temperature of the solar cell surface at various angles of the solar cell panel at 13:00.

From the above data, 13:00 provides the maximum light intensity and temperature of the solar panel surface. Energy demand tends to be higher in the 11:00 - 16:00 time frame. Naturally, this is the period when the price of electricity peaks. Solar energy happens to reach its maximum production capacity during those hours. Electricity produced at that time has a higher value than if it was generated at night. With the additional electricity input of solar energy, prices in those time frames could be driven down to a level close to those of night hours.

3.3 Analysis of solar-powered screw pumps

From the above experimental results, the performance of the screw pump depends on the n, the number of screws, and the θ. The linear graph of Q and $\dot{m}$ is increased with n increasing but the linear graph of Q and $\dot{m}$ is decreased with the angle of θ increasing. The volume flow rate and the $\dot{m}$ are proportional to the n and they are inversely proportional to the θ. They can also be written by the straight-line graph and the correlation is shown as $Q \propto \dot{m} \propto n \propto 1/\theta$. In addition, the performance of the screw pump must be considered to create a suitable design. In the case of the low motor speed (n = 10 rpm), the quantity of water flow is not sufficient for the agricultural system when using a low number of screws (N = 1 - 2). The quantity of water flow is rapidly increased with a medium number of screws (N = 3) but the quantity of water is only slightly increased with a high number of screws (N = 4). It can be seen that the weight of the water is important in the real system. With the high number of screws, the weight of the water is resistant to the upward flow so the quantity of water is not clearly increased. However, a high number of screws produce better performance than a low number of screws. In the case of the medium motor speed (n = 40 - 70 rpm), the quantity of water is increased with the number of screws increasing. In the case of the high motor speed (n = 100 rpm), the quantity of water is clearly increased with the number of screws increasing.

The parameters of the screw pump are investigated for both the experimental and numerical results. The solid modeling computer-aided design is numerically investigated. In this study, θ is fixed at 15° and n is varied from 0 – 100 rpm, as shown in Figure 12. The results show that both the volume flow rate and the $\dot{m}$ are increased as the n increases, as shown in Figures 12 (A) and 12 (B), respectively. When the number of screws is fixed (both at N = 1 and N = 3), the linear graph shows a similar trend so simulation results have good agreement with the experiment results. Figures 13 and 14 show the power (P) and η of the screw pump at various motor speeds. The n is varied from 0 – 100 rpm by increments of 10 rpm and N is varied from 1 – 4 by increments of 1. From the figures, the power and the efficiency are increased with the n. The power and the η of the screw pump are proportional to the n, and they can also be written by the straight-line graph with the correlation shown as $P \propto \eta \propto n$. Figure 13 shows the power of the screw pump at various angles of the screw pump. From Figure 13 (A) (N = 1), the power of the screw pump is gradually increased with the n and it is clearly increased with motor speed increasing as shown in Figure 13 (B - D) (N = 2 - 4). The power of the screw pump is fairly obviously decreased with the angle of θ increasing. In the case of θ = 75°, the power of the screw pump is gradually increased with the n increasing. The steepness of mechanical devices is important in a real system and that the θ increasing can reduce the water flowing upward. The η of the screw pump at various motor speeds and angles of the screw pump is shown in Figure 14. The η of the screw pump is increased with the n and the number of screws increasing. In the case of θ = 30° (Figure 14 (A)), the η of the screw pump is lower than in case of θ = 60° (Figure 14 (B)). The steepness of mechanical devices effect, and the power and the η of the screw pump are high. Furthermore, the performance and the efficiency of the solar energy depend on the α and the time progress. The α is 15° and 13:00 provides the maximum light intensity and temperature of the solar cell surface because it can more easily collect the light intensity and raise the temperature than in other cases.

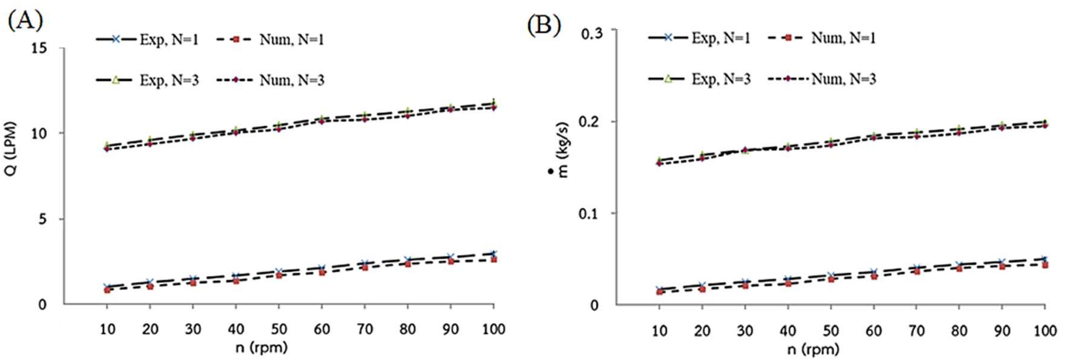

Figure 12 Comparison between experimental and numerical results when θ=15° and N = 1 and N =3: (A) the volume flow rate; (B) the $\dot{m}$.

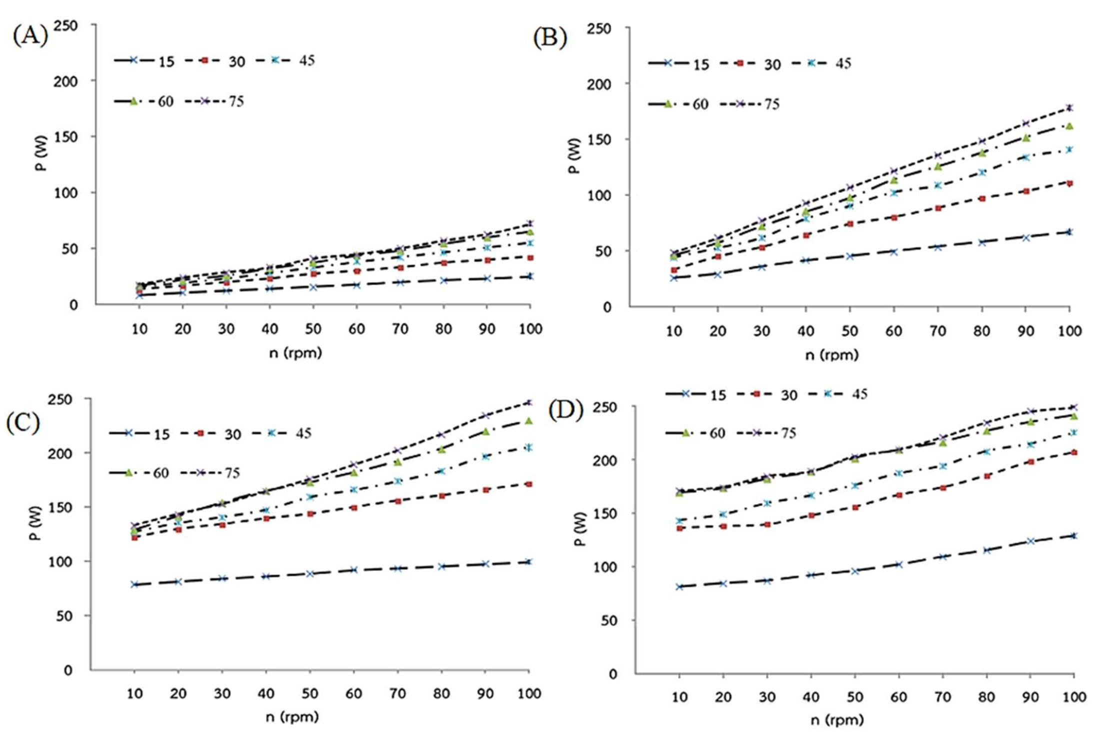

Figure 13 Comparison between the power of the screw pump and motor speed at various angles of the screw pump and numbers of screws: (A) N = 1; (B) N = 2; (C) N = 3; (D) N = 4.

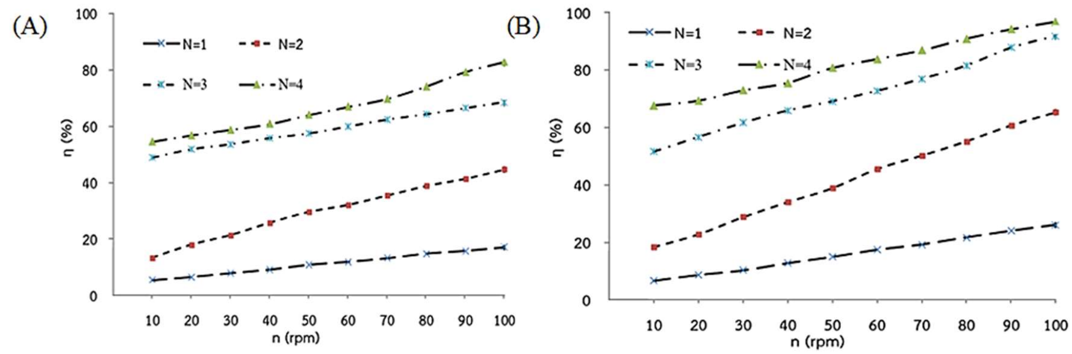

Figure 14 Comparison between the η of the screw pump and the n at various numbers of screws and angles of the screw pump: (A) $\theta = 30^{o}$; (B) $\theta = 60$.

The feasibility analysis for the solar-powered screw pump is calculated by the net return and payback period. The payback period (PP) is the fundamental force driving capital investment decisions. From the calculation, the solar-powered screw pump is compared with the screw pump into electrical energy. The solar-powered screw pump is composed of an electric motor and screw pump prototype. The initial investment of the solar-powered screw pump is THB 13,700 (457.06 USD) and it is divided into two main parts. The first part, the screw pump prototype, is THB 5,300 (176.82 USD). In the second part, the solar cell test equipment is THB 8,400 (280.24 USD) and it is calculated with the solar cell panel, battery, charge controller, and the solar inverter. The operating cost of the solar-powered screw pump is considered every 4 yrs. at THB 2,500 (83.41 USD) due to *the deterioration* in *battery* systems. The electricity prices are not considered for the solar-powered screw pump but are calculated for the screw pump into electrical energy. The electricity prices are the return of the solar-powered screw pump. The Ministry of Energy defines electricity prices and the electricity prices are dependent on many factors including government taxes. For feasibility analysis, the electricity prices are increased by increments of THB 0.2 for every year. The operating time is 6 h per day and 22 days per month. From the estimation, the initial payback period of the solar-powered screw pump is 7.83 yrs. when using it for 9 yrs. It can be seen the solar-powered screw pump is more feasible than the screw pump into electrical energy when used over long time periods.

4. Conclusion

The experiment is carried out to study the performance and the feasibility of the solar-powered screw pump based on the different angles of inclination. The following are the conclusions of this work. For the solar-powered screw pump, the volume flow rate and the $\dot{m}$ are increased as the n and the numbers of screws increase, and they are increased with the θ decreasing. The temperature of the solar cell surface shows a similar trend to the light intensity. From the calculation, the solar-powered screw pump is more feasible than the screw pump into electrical energy when used over long time periods. From the results, the linear graph of Q, $\dot{m}$, P and η. Finally, the P and the efficiency are increased with n increasing but the linear graph is decreased with the θ increasing. The correlation is $Q \propto \dot{m} \propto P \propto \eta \propto n \propto 1/\theta$. This research paper can be used as guidance for the special design of solar-powered pumps with a multiple screw design in order to develop the performance and feasibility of conventional pumps for irrigation and agricultural development in Thailand.

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