

CHAPTER 1 INTRODUCTION

1.1 Background

Windmills have been in use for many centuries for pumping water, United Nations Economic and Social Commission for Asia and the Pacific. Major, S. et al [1] produced a wind map for Thailand, which combines and updates the wind speed data previously available. Thailand experiences generally very low wind speeds with typically average speed of not above 3 m/s. According to a report on wind resource assessment of Thailand done by the Department of Energy Development and Promotion (DEDP) in 2001, the fair wind areas in the Class 1.3 to Class 2 category (4.4 m/s wind speed at 50 m height) or higher are located on the west side of the Gulf of Thailand as shown in Figure 1.1 [2]. There are three basic types of windmill in active use for water pumping in Thailand; the slow speed sail rotor type, the high speed wooden rotor type and the multi-blade steel rotor type [3].

For at least 60 years, locally constructed windmills have been used for salt farming. The Thai bamboo mat windmills or a Thai sail windmill that is a type of slow wind speed turbine [4], are widely in use in Thailand in the region near Samut Sakorn and Samut Songkram as shown in Figure 1.2. A large number were made with sail rotor diameter varying between 7 to 9 meters. These windmills are actually constructed from wood, bamboo and cloth materials which often carry six triangular sails as shown in Figure 1.3. Power is transmitted by a chain coupled to a ladder pump. The operating data, starting wind velocity is 1.7 m/s, average discharge is 17.3 litres/sec at pumping head 0.6 m and average wind speed 17 km/h [4]. The commercial Thai sail windmill are suitable for water pumping in salt farm which fixed in azimuth, rotating one way in the southwest monsoon and reversing direction in the northeast monsoon [4, 5].

Cretan windmills is a type of sail windmill such as Thai sail windmill, used for grinding corn in the Greek island, used for pumping water for on Great. The Cretan-type windmill is particularly effective for low-speed winds ($< 5\text{m/s}$) [6]. The characteristics of sail mill, observations were of brake load and speed found that, for high starting torque but moderate power follow from the use of large loosely sheeted sail, for higher power can be achieved at a higher speed but at the expense of starting torque by the use of large sails on alternate arms, or by the use of small sails on all the arms [7].

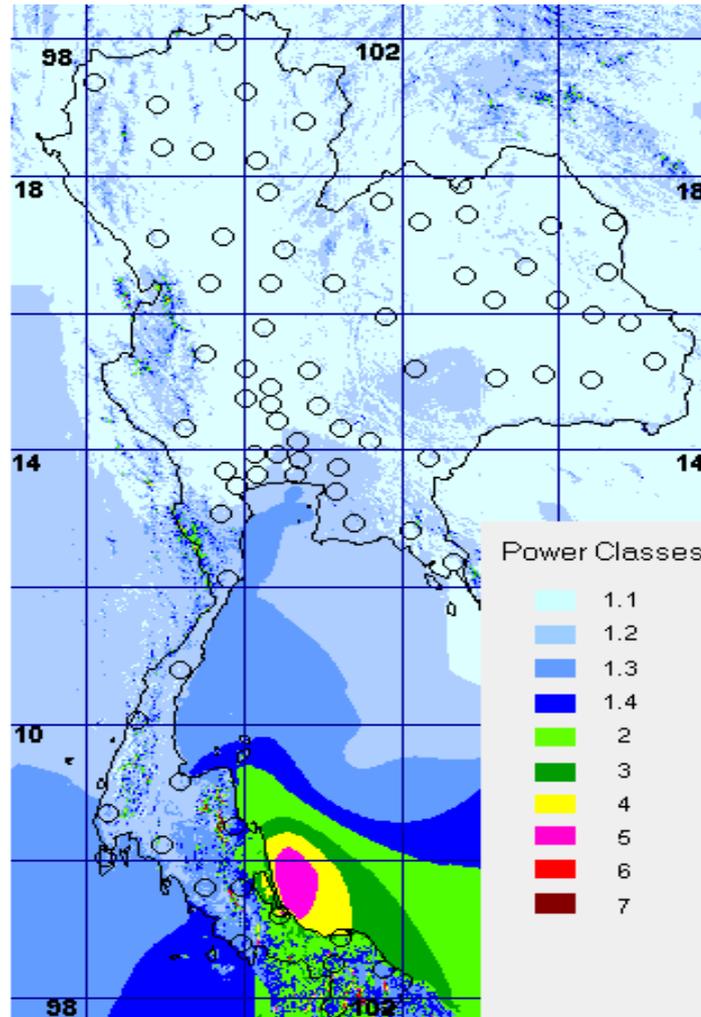


Figure 1.1 Wind map of Thailand [2]

Windmills work on the principle of converting kinetic energy of the wind to mechanical energy. The main component of a windmill is the rotor assembly which consists of sails blades attached to spokes radiating outward from a hub. The hub is mounted on a shaft that is capable of rotating on bearings. The pressure of the wind makes the sail or blade assembly turn on its axis and this rotation of the shaft can be used for operating a water paddle pump. The power developed is directly proportional to the area swept by the blades and the cube of the wind velocity. Windmills designed for multidirectional winds have a vane attached to the turntable. This vane intercepts the changing wind direction and orients the rotor to face the wind. Horizontal axis windmills having a large number of blades or sails have a high starting torque and are ideally suited to water pumping applications. The shaft power is transmitted to the water paddle pump.

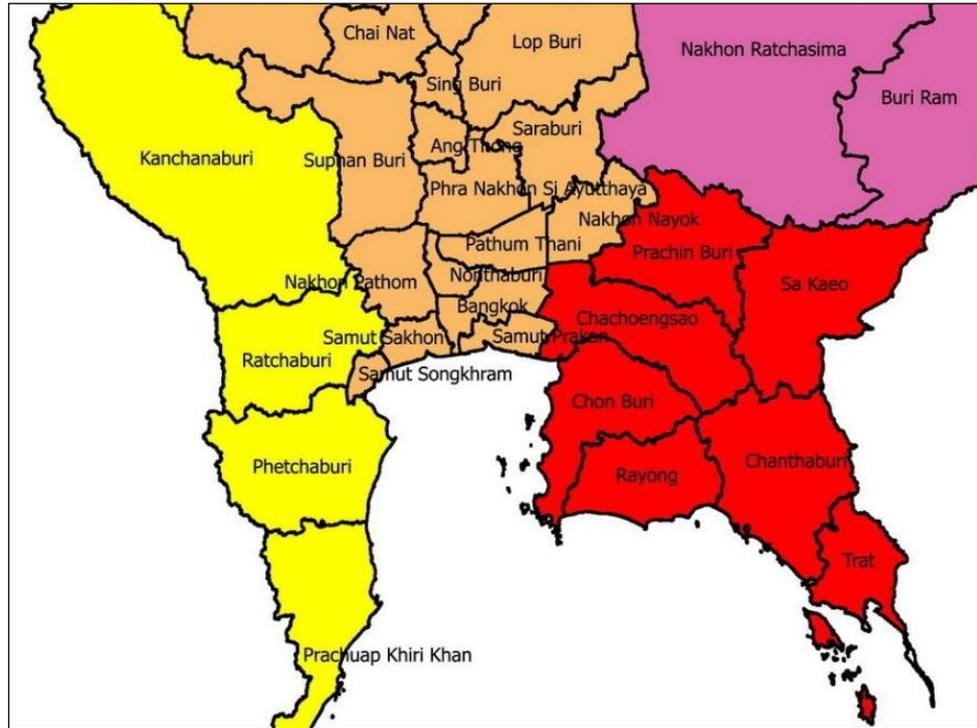
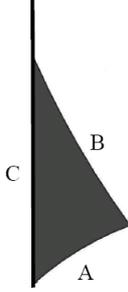


Figure 1.2 Samut Sakorn and Samut Songkram province of Thailand

Field survey of the local wisdom of a Thai sail windmill at the salt farm was conducted in the region near Samut Songkram of the horizontal axis windmill, slow-speed, bamboo-mat sail windmill or cloth sail windmill. The characteristics of the Thai sail windmill at the salt farm as shown in Table 1.1. The Thai sail windmill consists of five major components: rotor assembly, sails, power transmission, tower structure and pump as shown in Figure 1.3.

Table 1.1 Size of six blades Thai sail windmill salt farm

SIZE OF WINDMILL	DIAMETER (m)	A (m)	B (m)	C (m)	REMARK
Small ($\phi < 8$ m)	6.7-7.8	1.5-1.7	2.3-2.4	2.7-3.0	
Medium (ϕ 8-9 m)	8.1-8.9	1.6-1.9	2.3-2.9	2.7-3.4	
Large ($\phi > 9$ m)	9.1-9.3	1.6-1.8	2.7-3.2	3.2-3.8	

Rotor assembly: The rotor which is 7 to 8 m in diameter consists of a 30 cm diameter wooden hub mounted in the centre of a 5 m long, 10 cm square main shaft. Six bamboo spars radiate from the hub, the tips of each spar are braced by steel wires to points near the opposite ends of the main shaft. Each end of the main shaft is rounded to fit in a notch cut in the top of each of the two vertical wooden supporting poles.

Sails: There are 6 sails blades as shown in Table 1.1, made of triangular mat woven from split bamboo or cloth and reinforced with nylon cord. Each sail is fastened by wooden slats and nails along its long edge to a bamboo spar radiating from the hub. The apex of each sail is held tight by a nylon cord loop connected to a 1 cm diameter nylon rope which is stretched around the rotor circumference between the tips of each spar. A manually activated, quick-release sail-feathering device is incorporated at each loop connection.

Power transmission: Power is transmitted 12 m diagonally by a steel chain of 2.5 cm along open-links, from a 0.7 m diameter wooden pulley mounted at one end of the main shaft to a 6.5 m diameter wooden pulley near the ground which drives the power shaft of an open-trough wooden-pallet chain pump.

Tower structure: The stationary support structure of two wooden poles is set in the ground in a fixed direction to receive the winds of the southwest monsoon from one side and the winds of the northeast monsoon from the other side.

Pump: The open trough square-wooden pallet chain pump or water ladder pump used with the windmill. The size of wooden pallets normally is 15 cm width. The size of water ladder pumps is 15-18 cm width, 3.0-5.0 m long and 0.45-0.55 m high. The water ladder pump coupled by diagonally by a steel chain connected to windmill.

The main research questions are as follows:

1. How to improve the design of aerodynamic of the Thai sail windmill for low wind speed in Thailand?
2. What is the suitable and economical pump for low head operation coupled to the Thai sail windmill for water pumping?

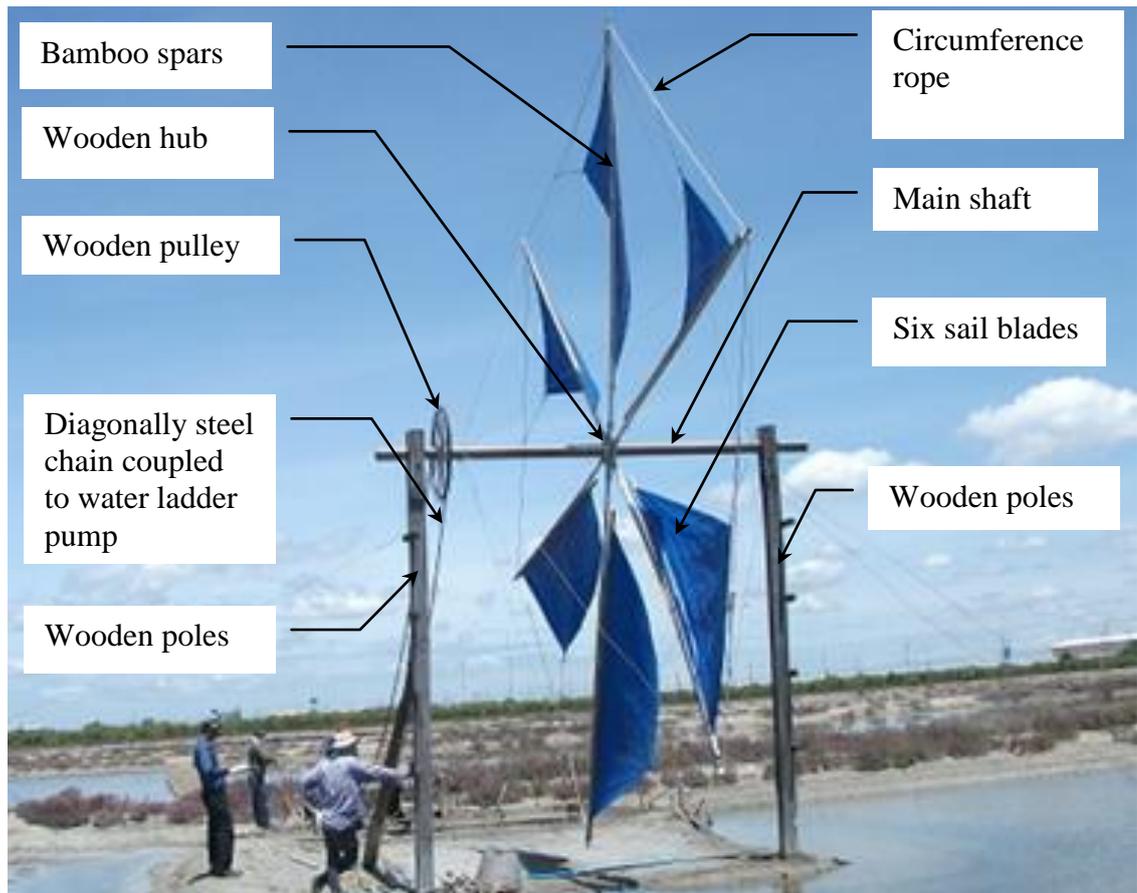


Figure 1.3 Thai sail windmill at the salt farm [5]

This dissertation objective is to study of the local wisdom of the slow speed sail rotor type of windmill in Thailand actually know as "A Thai sail windmill" and develop a new generation of the Thai sail windmill for water pumping to be used at any location of low wind speed in Thailand which not fixed to wind direction. To this end, we conduct experimental investigation on Thai sail rotor model (TSRM) in an open jet wind tunnel to determine the optimum power coefficient and torque coefficient of the model by varying several geometrical parameters. To conduct experimental investigation on Archimedeane's pipe-screw model (APSM) testing apparatus to determine the optimum of Archimedeane's pipe-screw pump. Then a prototype of new Thai sail windmill for water pumping coupled to water ladder pump and Archimedeane's pipe-screw pump to use for area of multi directional was constructed. Its design included a vane to intercepts the changing wind direction and orients the rotor to face the wind. Filed testing was conducted at Rajamangala University of Technology Rattanakosin, Nakhon Pathom province of Thailand.

1.2 Objective of the dissertation

The dissertation main objectives are the following:

1. Improvement the design of aerodynamic of the Thai sail windmill suitable for low wind speed in Thailand, so that it could be used in different locations and under various wind directions.
2. To develop a simple and economical pump for low head water pumping to be coupled to the new design of the Thai sail windmill.
3. To determine the overall efficiency and evaluate the economy of the system.

1.3 Scopes of the research work

The scopes of the research work are the following:

1. Study of local wisdom of a Thai sail windmill which is relatively simple to construct.
2. Laboratory scale testing by design improvements of the Thai sail rotor model, using laboratory scale experimental set up.
 - The blade of Thai sail rotor model made from cloth.
 - Identification of optimum design configuration of the Thai sail windmill through wind tunnel experiments.
 - The experimental investigation examined in the influence of the following variables on the above characteristics such as solidity of wind rotor by varied the number of sail and the size of the sails.
3. Laboratory scale testing by designs improvements of Archimedean's pipe-screw model (APSM).
 - The blade of Archimedean's pipe-screw model is small rubber pipe.
 - Optimum design configuration of Archimedean's pipe-screw model which Archimedean's pipe-screw model experiments.

- The experimental was examined in the influence of the following variables on the above characteristics such as pitch of pipe screw.

4. Large scale testing by designs improvements of the prototype of the new Thai sail windmill generation.

- The blade made form clothes or canvas sail which is a local material.

- The windmill can turntable to rotate when the wind direction changes.

- The maximum of rotor diameter is about 8.0 meters and maximum height of tower is less than 9.0 meters.

- Performance tests of the Thai sail windmill complete prototype model in field study.

5. Large scale testing, investigation of the Thai sail windmill for water pumping operation as follow:

- To study the existing windmill water pumping system such as water ladder pump and Archimedean's pipe-screw pump.

- To improve the existing windmill water pumping system by selecting appropriating pumping system by using Archimedean's pipe-screw as the main criteria for water pumping system.

- Coupled to water ladder pump for low head, length is about 4.0 meters.

- Coupled to Archimedean's pipe-screw pump for low head, is about 4.0 meters.

6. To evaluate economy of the system for water pumping.

1.4 Research methodology

1. To study literature review of wind energy for water pumping.
2. Field survey by local wisdom of a Thai sail windmill for improvement in laboratory scale testing and large scale testing.
3. Laboratory scale testing, which there was tested Thai sail rotor model (TSRM) through wind tunnel and the model test of Archimedean's pipe-screw model (APSM).
4. Analyze a result of laboratory scale testing, by Thai sail rotor model (TSRM) through wind tunnel experiments test which optimize the design of a Thai sail windmill, analyzed the result of tested model of Archimedean's pipe-screw model (APSM) which optimized the design of pump, and Use the best model to modify the prototype of large scale testing.
5. Large scale testing, There were construction of the new prototype of Thai sail windmill and field performance of the new Thai sail windmill for water pumping of the best model coupled to water ladder pump and Archimedean's pipe-screw pump.
6. Analyze the result of large scale testing with the prototype field testing, analyzed the result of prototype and data analysis, and determined overall efficiency of the system.
7. Cost of windmill for water pumping to evaluate economy of the system.
8. Conclusion and recommendation, to summarized the experimental result, conclusion and recommendation for future work.

1.5 Expected benefit of the study

1. Guideline to design an efficient of Thai sail windmill for low wind speed in Thailand.
2. A prototype of a Thai sail windmill in the turntable to rotate which is relatively simple to construct and has relatively high performance for water pumping system.
3. A prototype of the new generation of the Thai sail windmill for water pumping coupled to water ladder pump, Archimedean's pipe-screw pump which appropriate for water pumping system.

CHAPTER 2 LITERATURE REVIEW AND THEORETICAL CONSIDERATIONS

2.1 Literature review

Kanaki, M. T.; Probert, S. D. (1979) [6] studies about tip speed/wind speed ratio calculations are presented for Cretan-type windmills. The design of Cretan windmills incorporates a near-horizontal shaft with radial spars carrying triangular canvas sails whose bases are towards the circumference of the mill. The edge of each sail is attached to a spar, with the opposite corner secured to an adjacent spar by a cord. The spars are stayed together at the tips and the entire structure is supported by wires connecting the forward extension of the shaft to the outer tips of the spars. These systems are particularly efficient at low wind speeds (less than 5 m/sec) and are easily constructed. They offer a potentially useful source of energy for developing countries.

P.D Fleming and S.D Probert (1984) [8] produced theoretical understanding of the mode of operation of propeller type wind-turbines is now well established, whereas even preliminary theoretical analyses of the behaviours of flexible-sail type wind-turbines are virtually non-existent. This paper presents a preliminary stage in the process of rectifying this omission. Previous theoretical investigations about the pertinent aerodynamics of yacht sails are reviewed and their possible modifications to describe the behaviours of flexible-sail wind-turbines discussed.

Fleming, P. D. et al (1983) [9] produced the power harnessing advantages of using hub fairings either rotating or stationary, with or without stationary after bodies have been measured experimentally. For the flexible sail wind turbines tested, stationary (rather than rotating) hub-fairings produced greater power augmentations. Employing a stationary after-body is also desirable for the turbine in order to increase the rate of harnessing of wind energy.

Fleming, P. D. et al (1984) [10] produced previous investigations have shown that the maximum power outputs from small, horizontal-axis wind-turbines can be significantly increased if tip-fins and centre-bodies are added to the turbine. This paper describes quantitatively the effects of employing these two power enhancement devices simultaneously, and presents further optimisation data for tip-fins when used in conjunction with a centre-body augmented rotor.

Fleming, P. D. et al (1982) [11] produced a history of the development of wind powered machinery is presented, and the installation of tip vanes and center bodies to enhance the performance of low cost WECS for developing countries are examined experimentally. Particular attention is given to sail wing rotors equipped with tip fins, peristaltic pumps repairable by semiskilled labor, and various configurations of tip fins and center bodies, which deflect the wind outward from the hub to the sails. Cheap, flat-plate tip fins were found to effective in augmenting rotor performance by as much as 1.6 when facing only downwind. Best results were obtained with one tip vane per sail, with the fins downwind a distance at least equal to the pitch of a wind-filled sail. Further experimentation with stationary deflectors which redirect wind into the buckets of a Savonius rotor or the sails of a horizontal axis WECS are suggested.

Fleming, P. D.; Probert, S. D. (1982) [12] produced a Cretan-type windwheel is attractive because of its design simplicity, low cost, durability and ease of construction by semi-skilled labour from a variety of indigenous materials. Utilising a 0.64 m diameter cycle wheel as the structurally strong framework for the windwheel sails provides a rotor that is sufficiently rigid, relatively cheap (especially if the wheel and axle are cannibalised from an abandoned bicycle) and readily available throughout the world. Sail manufacture, assembly and maintenance for a Cretan windwheel can usually be undertaken locally, so eliminating the high costs of importing commercially available wind energy conversion systems. Thus, Cretan-type windwheels are likely to be increasingly used in less developed countries despite their intrinsically poor capabilities for harnessing wind power. Test data for a shrouded version of the 'cycle wheel', Cretan system are presented. The use of nine loosely sheeted sails produced a maximum power output of 14 W for an air speed at entry to the rotor of 5 m s^{-1} , corresponding to a free stream wind of less than 3.5 m s^{-1} . For this system it was found that tight (rather than loose) sails harnessed relatively little power. The presence of the shroud, which reduced tip losses, led to higher power coefficients being attainable. The mill was tested in rim-attached and sail-with-pole configurations. Winds shape the sails into airfoil shapes, and the addition of the shroud to augment the wind flow boosted the power coefficient to close to the Betz limit. The sail-with-pole form, comprising a loosely sheeted sail with the leading edge wrapped around the spoke and fastened to itself was found to be a practical configuration for driving a peristaltic pump. Maximum power was obtained with a higher rotor speed than the rotor speed for maximum torque. Two possible

applications for a larger version (than tested) shrouded, Cretan type windwheel are described, namely (i) for irrigation and land drainage in undeveloped countries and (ii) for stimulating a peristaltic pump which acts as a gravitational boost to drive solar-heated anti-freeze liquid around a low height, domestic central-heating circuit.

Triavanit, K. (1986) [13] produced performance of wind rotor used in Thailand by testing wind rotor models in wind tunnel and by simulation program calculation. Five models of windmill have been tested at various wind speed and wind rotor shapes. It is found that at Reynolds number 1.5×10^4 , USA-multiblade give maximum power coefficient of 0.21 at tip speed ratio 0.92, Bicycle wheel give maximum power coefficient of 0.34 at tip speed ratio 1.36. At Reynolds number 7.4×10^4 , Thai wooden-rotor with 2 blades give maximum power coefficient of 0.18 at tip speed ratio 7.9 while the same wind rotor with 4 blades give maximum power coefficient of 0.37 at tip speed ratio 5.9, Sail rotor with 6 blades and 20 degree blade give maximum power coefficient of 0.15 at tip speed ratio 1.0, Pattani wind rotor with 2 blades give maximum power coefficient of 0.14 at tip speed ratio 2.0.

Mukhia,P. (1981) [14] conducted to investigate the performance of the Thai 4-blades wind rotor coupled to a wooden ladder pump as used extensively for irrigation in the Chachaeng Sao Province. The rotor is locally constructed by individual farmers, while the ladder pump is manufactured in a Mechanical Shop at Chachaeng Sao town. From the rotor tests performed in the wind tunnel, taking into account the varying profiles and angles of each blade and also the aerodynamic losses, maximum power coefficient of 0.328 at tip speed ratio 5.5 has been estimated.

Iqbal, M.J. (1981) [15] produced the field measurements carried on the Thai multi-blades windmill "Sanit-14" and also the results of wind tunnel tests on the blade profile of the Sanit rotor, which uses a flat plate mounted on an angle iron. The field measurements at 2.75 m head shows that the system at this head has an overall efficiency of about 0.16 at a design velocity of 2.4 m/s. The output of 1 litre/sec, which is normally required for irrigation, attained at a wind power of 3 m/s. At 4.75 m and 6.75 m head the overall efficiency is 0.19 and 0.21 respectively, while output of 1 litre/sec is reached at wind speeds of 3.5 m/s and 4 m/s respectively.

S.K. Tewari and M.P. Ramesh (1985) [16] studies about method for regulation of small wind turbine rotors is described. The blade (a cambered surface in this instance) is provided with two span-wise slits which are normally kept closed with the help of chord-wise rubber strips or tension springs. In low wind speeds, the blade is a smooth arc, but it progressively distorts, resembling an inverted omega in moderate wind speeds. Such a distortion in the camber causes flow separation and results in rotor speed regulation. At higher wind speeds the gaps open-up, resulting in a reduced thrust coefficient, besides the power and speed regulation. This is a significant advantage over conventional spoiler regulation. Wind-tunnel test results for 1/10 and 1/5 scale models of a 7.5 m rotor diameter prototype are discussed, along with field data for the rotor power coefficient.

Ghosh, Pronoy. et al (2009) [17] produced horizontal and vertical axis type wind turbines using sails (instead of rigid blades) are experimentally investigated. Cretan type wind turbines are horizontal axis sail type wind turbines. The simple design, low cost and ease of construction of these turbines make them an attractive option for areas having low wind velocities. Coefficient of power and coefficient of torque for Cretan type rotor with 5 blades for a solidity ratio of 0.85 is studied. The type of the cloth used is polyester with porosity ranging between 75 to 300 μm . Experiments are conducted for Reynolds number of 1×10^5 and 1.2×10^5 and tip speed ratios ranging between 0 and 0.1. Influence of sail angle (5° , 15° , 25° and 30°) on the performance of the horizontal axis sail type wind turbines is investigated. Sail angle of 25° gives the maximum coefficient of power of 0.31 at a tip speed ratio of 0.71. Sail Savonius wind turbines are investigated on the vertical wind turbine domain. The enhanced performance of Cretan type wind rotors using sails laid the foundation for studying the behavior of Savonius wind turbines with flexible blades. The sail Savonius rotor used in the study has a rotor diameter of 180 mm with an overlap ratio of 0.15. The type of cloth used is polyester with the porosity ranging between 75 to 300 μm . The performance characteristic curves are measured for Reynolds number of 9×10^4 and 1×10^5 . The peak value of coefficient of power is around 0.05 at a tip speed ratio of 0.43 for a Reynolds number of 1×10^5 .

2.2 Wind energy in Thailand

In the past, the Asian Institute of Technology analysed of wind data. In 1980, Thavapaiaehandran calculated the available wind energy in Thailand, based upon hourly wind data of four locations: Haad Yai, Ubon, Bangkok and Chiang Mai. The average Wind speeds are rather low: from 0.8 m/s in Bangkok and Chiang Mai to 2.2 m/s in Ubon. This corresponds with theoretical available wind powers of 1.4 W/m²; and 28 W/m² respectively [18].

The potential of wind for power generation in Thailand. The results of surface wind analysis indicated that most of surface wind occurred during the day and reached the maximum around 1 PM.. The extent of the surface wind velocity, excluding calm was about 1.8-3.4 m/s [18].

The surface winds over Thailand are determined mainly by the monsoon circulation pattern. During the hot season from February to May, the air over south-east Asia has its origin in the trade wind from the pacific Ocean. During this period, wind over north-east Thailand and the peninsula are blowing from the east. In central Thailand, winds climate come under the influence of the south-west monsoon. November marks the onset of north-east winds which last till January [20].

In most parts of Thailand, the mean annual wind speed are below 3.0 m/s, while wind coastal regions in the Gulf of Thailand and on the Indian ocean side, stronger wind can be expected [20].

Thailand has a long history of wind energy utilization. The traditional Thai wind pumps with wooden blades and the sail-clothed wind pumps are still in use, particularly along the coastal belt in north of the Gulf of Thailand. Even through the wind speeds are generally low, the widespread use of wind pumping in Thailand may have been due to its use for low head applications [20].

The direction of surface wind in Bangkok was strongly affected by the southwest monsoon from May to September and northeast monsoon from October to February. Strong southern wind appeared in March. The frequent wind velocity was about 1-3 m/s while the annual mean value is about 2.2 m/s [21].

According to a report on wind resource assessment of Thailand done by the Department of Energy Development and Promotion (DEDP) in 2001, there are good wind areas during the North-East monsoon, starting from November until late of March. The areas in the Class 3 category (6.4 m/s wind speed at 50m height) or higher are located along the eastern coastline of the southern part of the Gulf of Thailand from Nakhon Srithammarat through Songkla and Pattani provinces, and also over the ridge of Doi Intanon in Chiangmai province. In addition, the assessment indicates that there are good wind areas during the South-West monsoon, from May until mid-October; they are located on the west side of Thailand stretching from the northern end of the southern region into the parts of the northern region. These areas occur in the mountain ranges through Phetchaburi, Kanchanaburi and Tak provinces. Good wind areas during both the North-East and the South-West monsoons are located in the mountains of the national parks in the southern region. These areas are in Krang Krung national park in Suratthani province, Khoa Luang and Tai Romyen national park in Nakhon Srithammarat, Sri-Phangnga national park of Phangnga, and Khoa Phanom Bencha in Krabi province [2, 22].

The fair wind areas in the Class 1.3 to Class 2 category (4.4 m/s wind speed at 50 m height) or higher are located on the west side of the Gulf of Thailand in Phetchaburi, Prachuabkirikan, Chumphon and Suratthani provinces. These fair wind areas also occur over mountain ridges in the northern region of the country at Chiangmai and in the north-eastern region in Phetchabun and Loei provinces, which are influenced by the North-East monsoon. They also occur under the influence of the south-west monsoon in the western coastal areas of the southern region at Phangnga, Phuket, Krabi, Trang and Satun, and also on the eastern side of the Gulf of Thailand in Rayong and Chonburi provinces [2, 22].

2.3 Wind pumps used in Thailand

Locally constructed windmills have been used for brine pumping along the Gulf of Thailand and for rice irrigation in the Chao Phraya delta for at least 80 years. There is no evidence, at present, that any low cost windmills are used in Thailand for electricity generation, although some people have tried to use two-bladed wood rotor windmills for D.C. generation [19].

There are three basic types of windmill in active use for water pumping; the slow speed sail rotor type, the high speed wooden rotor type and the multi-blade steel rotor type [19].

2.3.1 Slow speed sail rotor type

Several hundred 7 to 8 m diameter bamboo-mat sail rotors are used for brine pumping at the salt farms along both sides of a 10 km section of the highway near Samut Songkram. Each of the six sails of these windmills consist of a triangular mat woven from split bamboo and reinforced with nylon Chord [19].

About thirty cloth sail windmills are used for brine pumping at three salt farm areas near Chonburi, along the Bangkok Chonburi highway. This type of windmill is also known to have been used at Ban Laem, Petchaburi, the largest salt producing area in Thailand. A few years ago they were replaced by diesel and gasoline engine pumps because of the advantages of portability and greater control over water pumping, but now they are returning because of the increasing oil price and shortage of diesel fuel [19].

This windmill starts pumping at a wind speed of 2.2 m/sec and reaches optimum performance of 25 rev/min at 3.6 m/sec. The wind pump will increase speed up to about 40 rev/min in higher winds. The diameter of the pump is 7-8 m [19].

In 1986, Tiravanit K., determined the performance of wind rotor used in Thailand by testing wind rotor models in a wind tunnel and by simulation program calculation. Five models of windmill have been tested at various wind speed and wind rotor shapes. One of the rotor model was sail rotor with 6 blades and 20 degree blade gave maximum power coefficient of 0.15 at tip speed ratio 1.0 [13].

2.3.2 High speed wooden rotor type

High speed wooden rotor type windmills are commonly used for water pumping in the coastal provinces of Chachoengsao and Samut Prakran, South East of Bangkok. These windmills are used for lifting brine at the salt farms near Bang Pakong and water lifting for irrigation in the paddy areas surrounding Chachoengsao [14].

The rotors of these windmills consist of two or four wooden blades. Two blades are generally used nearest the coast in higher winds, while four blades are used inland where lower wind speeds would cause self starting problems for the two blade rotors.

Four blade rotors are sometimes used near the coast for higher lift and higher torque loads [14].

2.3.3 Multi-blade steel rotor type

Multi-blade windmills were introduced to Thailand more than ten years ago, and a local manufacturer is increasing his sales all over the country. This type of windmill is also used for pumping water. [19] Some performance data of wind pumps developed in hailand are presented in Table 2.1 [20].

Table 2.1 Performance data of some wind pump in Thailand [20]

Type	Diameter (m)	Pumping rate (m ³ /h)	Wind speed (m/s)	Head (m)
Canvas and cloth blade	6-8	46	3.6	0.6
Wooden : 2-4 blades	6-8	90	5.8	0.9
Multi-blade (USA)	1.8-7.3	0.42 with 3.2 m diameter	2.8	20

2.4 A Sail Windmill

Wind pumps have also been used in South East Asia and China for longer than in Europe, mainly for irrigation or for pumping sea water into drying pans for sea salt production. The Chinese sail windpump was first used over a thousand years ago and tens if not hundreds of thousands, are still in use in Hubei, Henan and North Jiangsu provinces . The traditional Chinese designs are constructed from wire-braced bamboo poles carrying fabric sails; usually either a paddle pump or a dragon-spine (ladder pump) is used, typically at pumping heads of less than 1 m. Many Chinese windmills rely on the wind generally blowing in the same direction, because their rotors are of fixed orientation. Many hundreds of a similar design of windpump to the Chinese ones are also used on salt pans in Thailand as shown in Figure 2.1, [3, 26].

Some 50,000 windpumps were used around the Mediterranean Sea for irrigation purposes. These were improvised direct-drive variations of the metal American farm windpump, but often using triangular cloth sails rather than metal blades. These sail windmills have a type of rotor which has been used for many centuries in the Mediterranean region, but today is often known as Figure 2.2 Cretan windmills. However Crete is well known as a country where until recently about 6,000 windpumps were still in use, mostly with the cloth sailed rig. The numbers of windpumps in use in Crete are rapidly declining and by 1986 were believed to be barely one thousand [3].

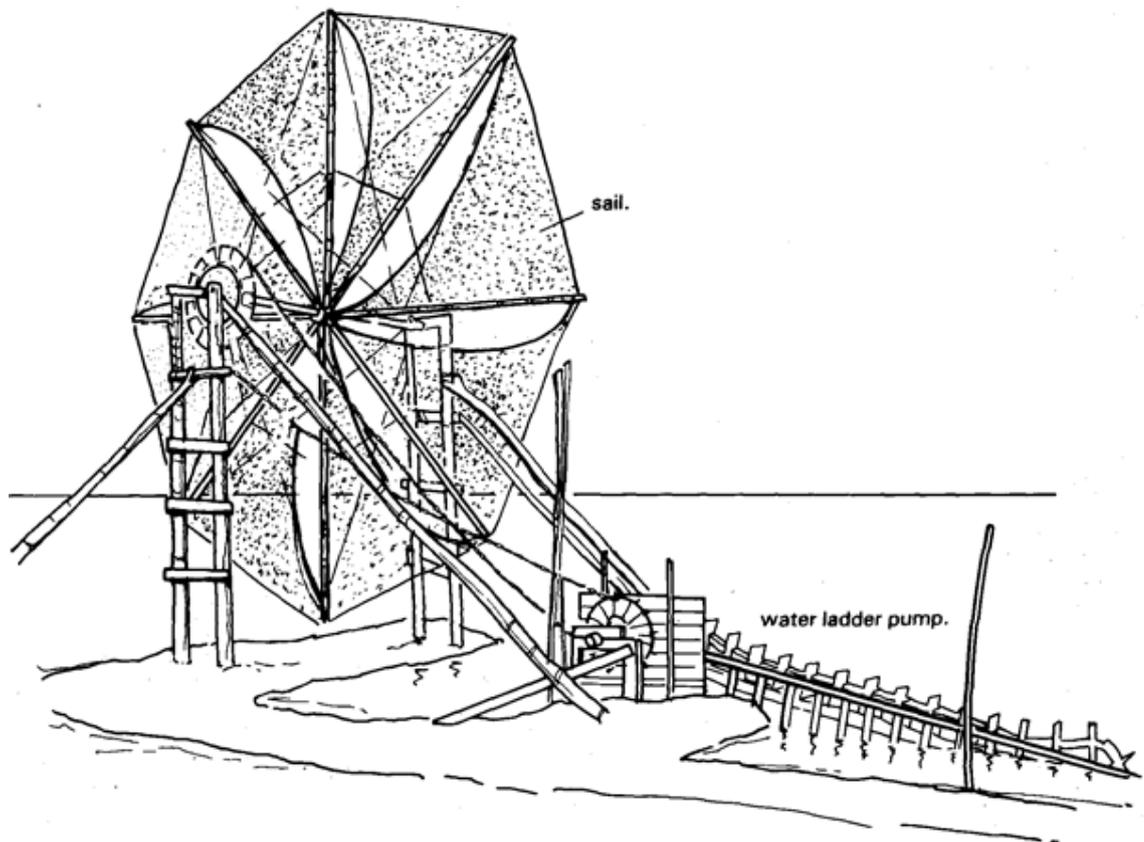


Figure 2.1 Thai windpump [23]

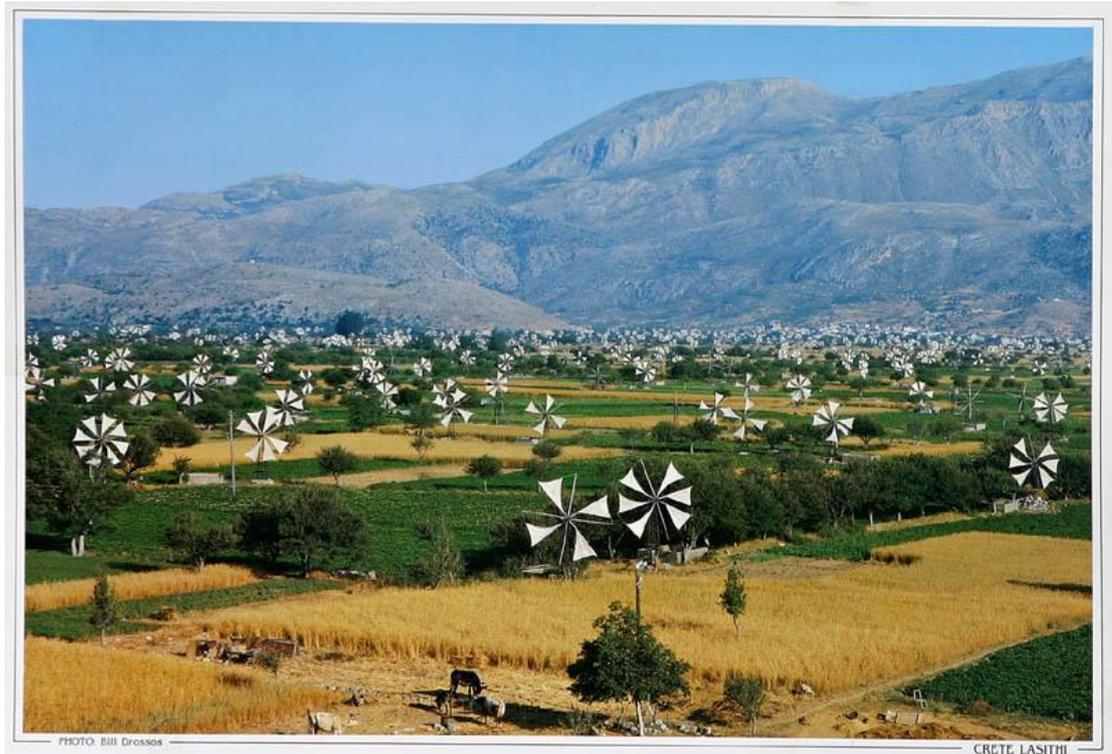


Figure 2.2 Cretan windmills use in Crete

The Collado windmill is located in the Andalusia, Spain. The sails of the collodo windmill was approximately 90 m^2 and high is 6 m. The Collado windmill, the runner turned at 35.5 rpm, with wind speeds of around 5 m/s and has a C_p value of 0.27 [24, 25].

2.5 Experimental methodology and measurement system

There are three basic methods of testing wind turbine rotors, each method having its own advantages and disadvantages, [27, 28].

1. Wind tunnel testing, the mainstay of the aircraft industry, has been of limited value in wind turbine rotor development. Wind tunnel could provide useful data, financial limits have restricted the size of tunnels that the wind industry can afford.
2. Tow testing, whereby the wind turbine is pulled or pushed through static air, can relieve the scaling and blockage problems of wind tunnels, but the rotor size is limited.
3. Field testing presents the proper wind environment, but it brings new challenges in measuring and recording test data; the method which was used in this case greatly smoothes the resulting graph of the power curve.

The experimental windmill rotor model for wind tunnel test and the rotational set-up to use in laboratory work. Uniform main flow is produced by an open-jet-type wind tunnel [29, 30].

2.6 Wind energy equation

For a horizontal axis windmill the general equation [13]-[25] for estimate of wind power equation (1) to (6) is:

The wind power (P_w) equation

$$P_w = \frac{1}{2} \rho A V^3 \quad \dots\dots\dots(1)$$

Where ρ is the air density, V is the wind speed and P_w is the power, A is the projected area of rotor.

The shaft power output (P_s) is measured by use of a simple frictional brake from the expression

$$P_s = T\omega \quad \dots\dots\dots(2)$$

where T is the brake frictional torque and ω is the rotational speed of the rotor.

The power coefficient (C_p) is the efficiency of conversion of wind energy into mechanical energy of the wind turbine. The power coefficient is the ratio of shaft power (P_s) to the power available in the wind (P_w) passing through a disc or shape having the same area as the vertical profile of the windmill rotor, and this indicates the efficiency of conversion, given by

$$C_p = \frac{P_s}{P_w} = \frac{P_s}{\frac{1}{2} \rho A V^3} \quad \dots\dots\dots(3)$$

The torque coefficient (C_q), which is a non-dimensional measure of the torque force on the drive shaft produced by a given size of rotor in a given wind speed. The torque coefficient, C_q , is defined as:

$$C_q = \frac{P_s}{\frac{1}{2}\rho AV^2 R} \dots\dots\dots(4)$$

where P_s is the actual torque at wind speed V for a rotor of that configuration and radius R .

The Tip Speed Ratio, TSR, the speed is also conventionally expressed non dimensionally as the "tip-speed ratio" (λ). This is the ratio of the speed of the windmill rotor tip, at radius R when rotating at ω radians/second, to the speed of the wind, V , and is numerically:

$$\text{TSR} = \lambda = \frac{\text{speed of rotor tip}}{\text{wind speed}} = \frac{u}{V} = \frac{\omega r}{V} \dots\dots\dots(5)$$

Rotor solidity (σ) is a fairly graphic term for the proportion of a windmill rotor's swept area that is filled with solid blades, is defined as:

$$\sigma = \frac{\text{area of solid blades}}{\text{windmill rotor's swept area}} = \frac{A_{\text{blades}}}{A_{\text{rotor}}} \dots\dots\dots(6)$$

Multi-bladed rotors, as used on windpumps, (eg. rotor "B" in Figure 2.3) are said to have high "solidity", because a large proportion of the rotor swept area is "solid" with blades. Such machines have to run at relatively low speeds and will therefore have their blades set at quite a coarse angle to the plain of rotation, like a screw with a coarse thread. This gives it a low tip-speed ratio at its maximum efficiency, of around 1.25, and a slightly lower maximum coefficient of performance than the faster types of rotor such as "D", "E" and "F" in the figure. However, the multi-bladed rotor has a very much higher torque coefficient at zero tip-speed ratio (between 0.5 and 0.6) than any of the other types. Its high starting torque (which is higher than its running torque) combined with its slow speed of rotation in a given wind make it well-suited to driving reciprocating borehole pumps.

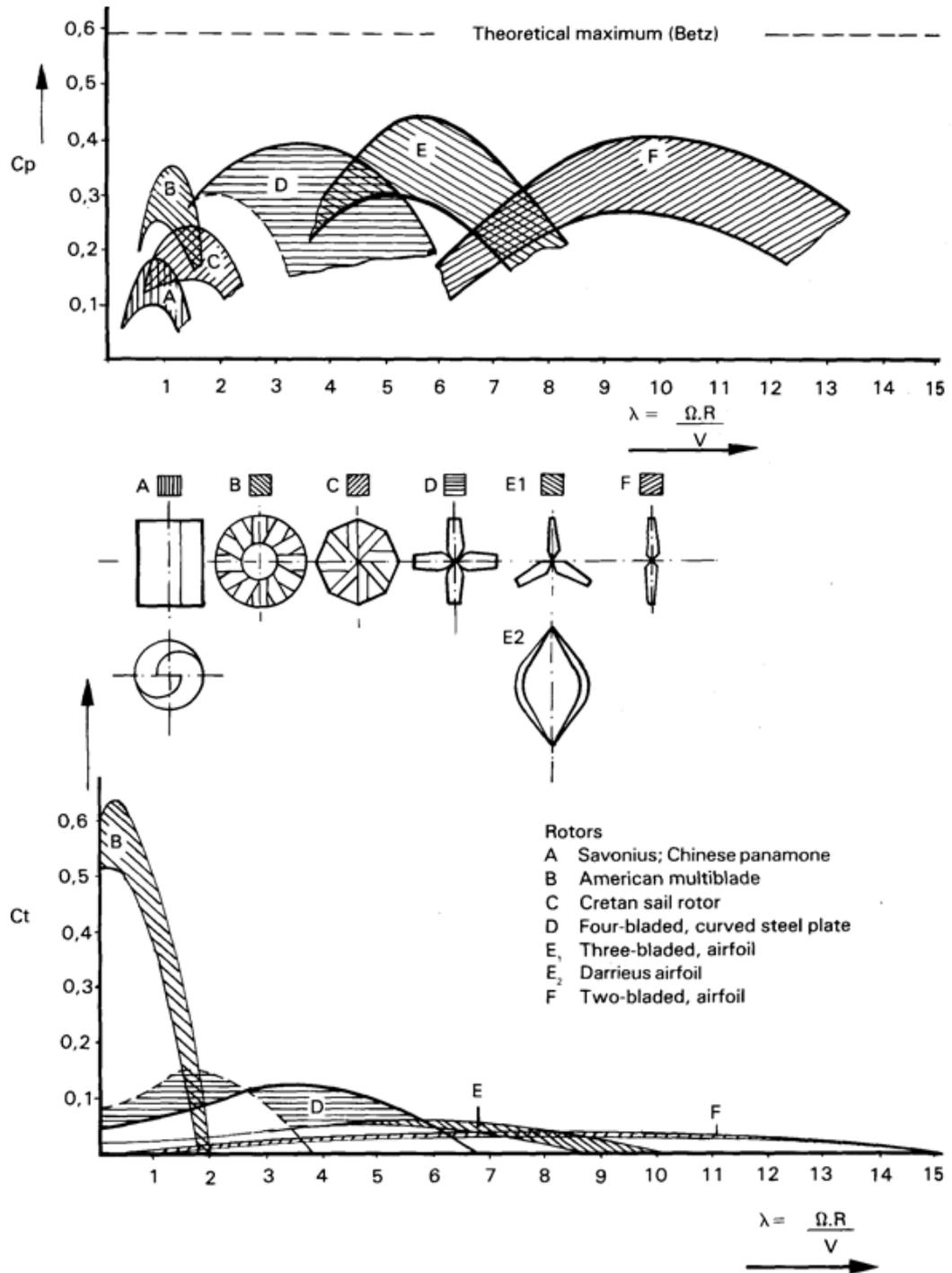


Figure 2.3 The power coefficients (C_p) (above) and the torque coefficients (C_t) of various types of wind turbine rotor plotted against tip-speed ratio (λ) [23]

2.7 Water ladders pumps

The water ladder is still very widely used on small farms in South East Asia for flood irrigation of small fields and paddies from open streams and canals or for pumping sea water into evaporation pans to produce sea salt. In China it is known as a "dragon spine" or dragon wheel" and in Thailand as "rahad". In most cases it is made mainly of wood, and can consequently easily be repaired on-farm. It is one of the most successful traditional, high-flow, low-lift water pumping devices and is particularly applicable to rice production, where large volumes of water are sometimes needed [23].

2.8 The Archimedean screw pumps

The progressive cavity pump is one of the more recent pump concepts to appear, while the Archimedean screw is one of the oldest, yet they have a number of similarities. The Archimedean screw pump, built since before Roman times and still used in a similar form in Egypt, is made up of a helix of square cross-section wooden strips threaded onto a metal shaft and encased in a tube of wooden staves, bound like a barrel with metal bands [23].

The Archimedean screw can only operate through low heads, since it is mounted with its axis inclined so its lower end picks up water from the water source and the upper end discharges into a channel. Each design has an optimum angle of inclination, usually in the region of 30° to 40° , depending on the pitch and the diameter of the internal helix. The principle is that water is picked up by the submerged end of the helix each time it dips below the surface, and as it rotates a pool of water gets trapped in the enclosed space between the casing and the lower part of each turn. As the whole assembly rotates, so the helix itself screws each trapped pool of water smoothly further up the casing until it discharges from the opening at its top; the water pools move much as a nut will screw itself up a bolt when prevented from rotating with it. This is also analogous to the trapped volumes of water screwed between the rotor and stator of progressive cavity pumps [23].

Traditional wooden Archimedean screws of the kind just described have been tested and found to have efficiencies in the region of 30% [23].

The modern version of the Archimedean screw is the screw pump, Figure 2.4. This consists of a helical steel screw welded around a steel tubular shaft, however unlike an Archimedean screw, there is no casing fixed to the screw, but it is mounted instead in a

close fitting, but not quite touching, semi-circular cross-section inclined channel. The channel is usually formed accurately in screeded concrete. Because of the clearance between the screw and its channel, some back-leakage is inevitable, but the total flow rate produced by a screw pump is so large that the backflow is but a small percentage. Therefore modern screw pumps can achieve high efficiencies in the region of 60-70% [23].

Probably the main disadvantage of screw pumps is that an elaborate transmission system is needed to gear down an electric motor or diesel engine drive unit from typically 1500 rpm to the 20-40 rpm which is normally needed. Mechanical transmissions for such a large reduction in speed are expensive and tend to be no more than 60-70% efficient, thereby reducing the total efficiency of the screw pump, including its transmission to about 50-60% [23].

The geometry of an Archimedes screw is governed by certain external parameters (its outer radius, length, and slope) and certain internal parameters (its inner radius, number of blades, and the pitch of the blades). The external parameters are usually determined by the location of the screw and how much water is to be lifted. The internal parameters, however, are free to be chosen to optimize the performance of the screw [34].

The Tjasker type is the simplest and smallest of the Netherlands water pumping windmills, Figure 2.5. It consists essentially of a long wooden shaft mounted at an angle of 30° to the horizontal, the upper end of the shaft carrying four cloth sails on a wooden framework, 6 m in diameter, and the lower end terminating in a closed Archimedean screw. The shaft is supported by a wooden A-frame and the assembly can be moved in a circle around a central pivot pole to point the sails into the wind [3].

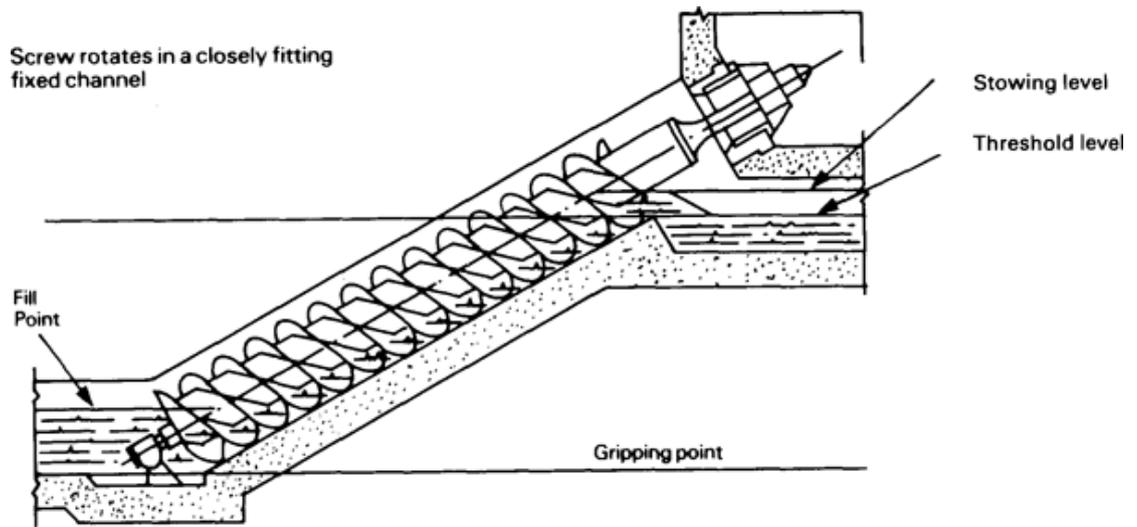


Figure 2.4 The modern of the Archimedean screw pump [23]

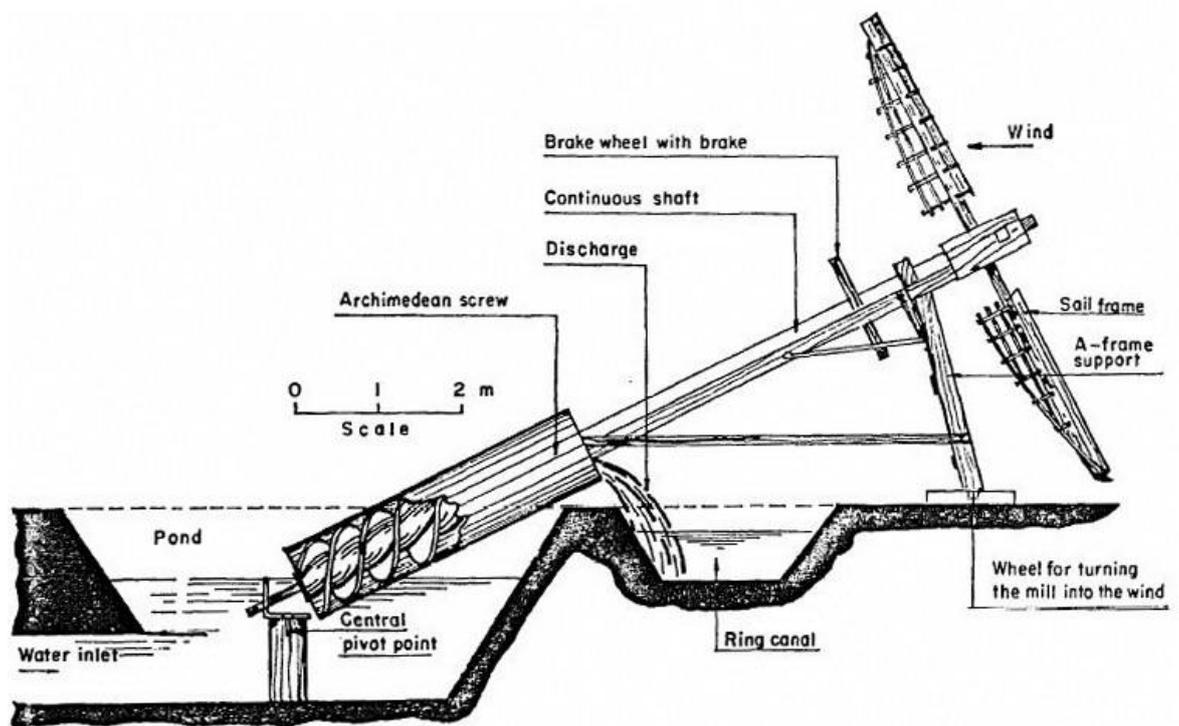


Figure 2.5 Netherlands "Tjasker"-type rotor and Archimedean screw pump [3]

2.9 Water pumping equation

The hydraulic power required to lift or pump water is a function of both the apparent vertical height lifted and the flow rate at which water is lifted [23].

$$P_{hyd} = \rho g Q H_a \dots\dots\dots(7)$$

Where P_{hyd} is The hydraulic power, ρ is density of water, g is acceleration due to gravity, Q is discharge or flow rate and H_a is vertical height

Power needs are related to the head (height water is lifted) and the flow rate. In reality, the actual pumping head imposed on a pump, or "gross working head", will be somewhat greater than the actual vertical distance, or "static head", water has to be raised. Figure 2.6 indicates a typical pump installation, and it can be seen that the gross pumping head, (which determines the actual power need), consists of the sum of the friction head, the velocity head and the actual static head (or lift) on both the suction side of the pump (in the case of a pump that sucks water) and on the delivery side.

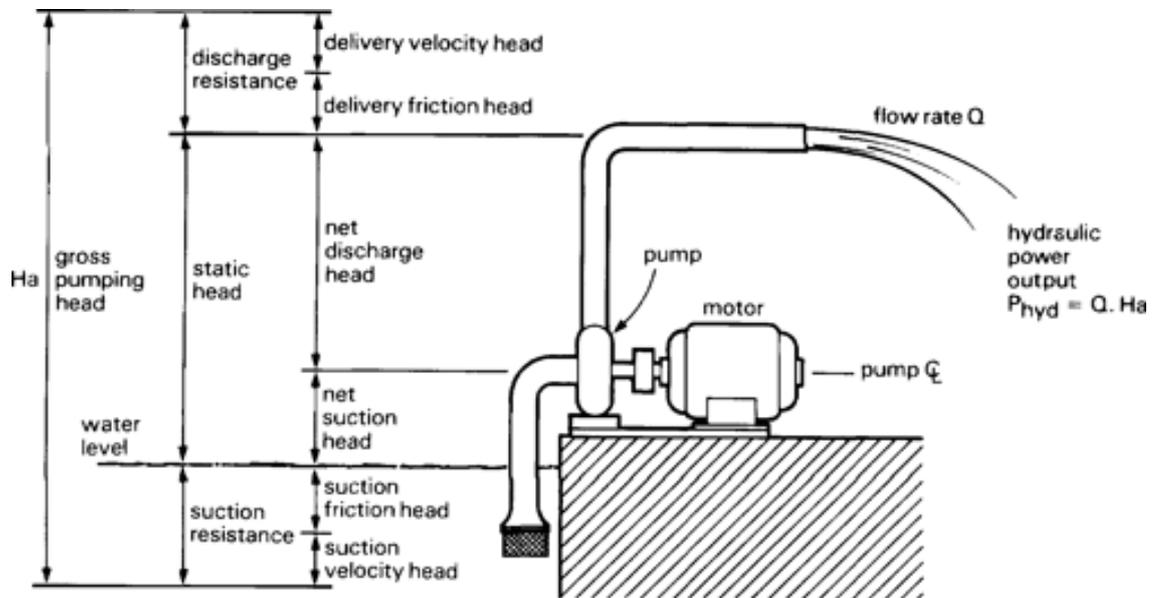


Figure 2.6 Typical pump installation

Efficiency of components; the importance of matching, the general principle that:

$$\text{Power} = (\text{head} \times \text{flow rate}) \dots\dots\dots(8)$$

and $\text{Energy} = (\text{head} \times \text{total weight of water lifted}) \dots\dots\dots(9)$

Applies to any water lifting technique, whether it is a centrifugal pump, or a rope with a bucket on it. The actual power and energy needs are always greater than the hydraulic energy need, because losses inevitably occur when producing and transmitting power or energy due to friction. The smaller the friction losses, the higher the quality of a system. The quality of a system in terms of minimizing losses is defined as its "Efficiency":

$$\text{Efficiency} = \frac{\text{Hydraulic energy output}}{\text{Actual energy input}} \dots\dots\dots(10)$$

using energy values in the equation gives the longer-term efficiency, while power values could be used to define the instantaneous efficiency [23, 35].