CHAPTER 2

LITERATURE REVIEW

In this chapter, the researcher conducted the study on natural water sources, the use of pumping systems and natural water sources, variables and appropriate technology, the performance of the pumping systems, and comparative economic analysis regarding capital.

Natural Water Sources

Water is one of the most essential natural resources. Water is important to humans, animals, and vegetation, moreover, it could be used for agricultural activities and to generate electricity (Vadhanaphong, 1999). Water came from 3 main sources, which were:

1. Rain water; Thailand is located in the area of monsoon climate which has 6 months of raining period. Therefore, most of the population is engaged in agriculture and mostly rely on rain water for their agricultural activities.
2. Surface water such as rivers, canals, swamps, and etc.; All of them provided the quantity of water which was related to the quantity of rain water. The increasing and decreasing of the surface water was according to the increasing and decreasing of rain water.

3. Underground water was the water that could be found underground or sometimes is called groundwater. Some portions of the water came of the rain water that saturates the surface, seeps underground, and turned into important river source of Thailand.

In the northern region, there are many crucial rivers such as Ping river, Wang river, Yom river, and Nan river. The four rivers combined to form the Chao Phraya river There was also some other smaller rivers such as Suphanburi river, Lopburi river, Nam Noi river and Phayao lake with 12,100 acres located in Phayao province. In the central region, there were more water sources than other regions of the country due to its water basin geographical location. Several rivers ran through the region such as Chao Phraya river, Tha Chin river, PhaSak river and well-known water source such as Bueng Boraphet swamp with the area of 30,100 acres. The northern-eastern region is the region that usually faced with water shortage problems due to the quantity of rain water in the region. In the eastern region, there are Bang Pakong river and Nong Han swamp with the area of 50,000 acres. The southern region has plenty of water and there are several important rivers such as Tapi river, KraBuri river, and Trang river.

As previously stated, Thailand is located in a good geographical location that offers many good potential water sources in many parts of the country that can be used for agricultural activities. These water sources are surface water sources and underground water sources. The study of water storage for community's agricultural activities will be conducted on surface water sources according to its types; water sources that fall from high level to lower ground such as waterfalls and weirs (Figure 2.1). When water falls from different height of ground, it will generate energy from water velocity which can benefit agricultural activities. There are plenty of water sources that flow from higher ground to lower ground such as river, canals, and streams, including the irrigation system established by the Royal Irrigation Department for agricultural activities.


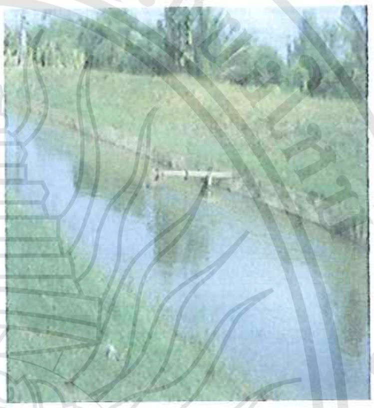

Figure 2.1 Natural water sources such as waterfalls and canal

Source: Saisunee Budhakooncharoen. (1997).

Water Pump

Water pump is a Fluid Machinery that adds energy to the liquid substance (especially water) and makes the fluid substance to have higher level of energy and able to move both in length and height aspects according to the appointed rate (Budhakooncharoen,1997). Water pump could be categorized into various types according to the nature of its use, water pump's materials, or substance used with the water pump. However, the easy method was to categorize by the features that are used to add energy to the liquid substance by the water pump, which could be categorized into 2 major groups. The first system is Dynamic Hydraulic Pump. This type of water pump continuously added in energy to the liquid substance and slowly added speed to the substance at the entry point until the substance reaches the highest energy level at the exit point. The example of this type of water pump was Centrifugal pump (Figure 2.2). The second system was Displacement Hydraulic Pump which would add energy to the liquid substance in the form of discontinuous cycle which was different from a dynamic system. The adding of the energy was done by a piston or diaphragm plate. The piston or diaphragm plate would drain the substance and push it out to the exit point, and the substance would reach the highest speed level at the exit point. The example of this type of water pump was a Diaphragm Pump.

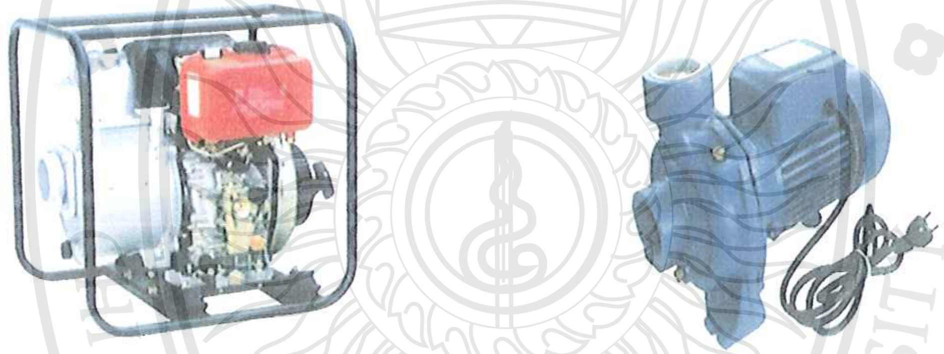

Figure 2.2 Centrifugal Pump with petrol and electricity as energy sources

Source: Saisunee Budhakooncharoe. (1997).

Hydraulic Ram Pump

Hydraulic ram pump is a water pump system which uses water as the power to operate by using the principle of the occurrence of water hammer similar to what happens when a water gate is suddenly opened. If the water in the pipe is flowing with high velocity, it will create water impact on the water gate when the gate is suddenly opened and will generate the high pressure inside the water pipe. If the pipe is big and long, the pressure will be higher and might break the pipe. Furthermore, it will also create the sound inside the pipe, known as the name "water hammer" which is an undesirable circumstance for irrigating by water pipes (Figure 2.3). However, the hydraulic ram pump can use the occurrence of water hammer to pump up water by relying on the impact inside the pipe that is suddenly stopped and make the pump to operate automatically. The energy generated the power and allowed the system to be able to pump up 1-2 times of the quantity of the water in the system from lower level to higher level. The quantity of the pumped water was less than the quantity of the water that was wasted away from using water as the power to operate the system. A certain portion of water will be pumped into the system and used and 10 – 15 % of the water quantity would be washed away. The quantity of the water derived depended on the performance of the pumping system.

Figure 2.3 Hydraulic ramp pump schematics

Source: Jennings, G.D. (2000).

The mechanism of hydro power pump started by the use of water that flowed from water source though water pipes and out through the water gate which controled the velocity and speed of the water. If the velocity that ran through the valve was high enough, the speed and pressure from water source would make the valve suddenly opened and created the impact between the water and the pipe's wall, and it would raise the pressure to higher level in rapid speed. The increasing pressure would make the valve of the air tank to open and allowed the water to flow in the pipe and go into the water tank. When the water was collected in the water tank, the pressure level would be lowered and the impact energy of the water would reflect back and the control valve would eventually be back to normal. After that, the water would flow into the system and the system cycle would start again. The performance of the hydro power water pump was the same as other pumping machines. It could pump up the water from lower level to higher level automatically and continuously and did not cost much for maintenance, moreover, it did not need lubricated parts and could be designed for its specific performance level. Crucial factors to make the pumping system operate effectively with maximum performance were: level of the water that flows into the system; the height level of the water that was delivered; the size of the pipe in the system; boiler; the length the pipes; the friction of the water inside the pipe; the rate of water loss which needed to be as at minimum rate; the modification of the valve that needed to be consistent; and pipe line connection.

Thailand has many waterfalls located in many provinces. Thai farmers employed the principle of the water that falls between 2 – 10 m from high ground to make a pumping system called hydraulic ram pump. The system employed the principle of water hammer, however, this technology had been invented for 210 years by a British engineer, John Whitehurst (1772). The system could operate without using any fossil energy. It operated with few mechanism and could be built and installed very easily with low budget. Therefore, this kind of pumping system was suitable for people in the rural area or the area with no electricity.

Few research focused on the in-depth analysis of hydraulic ram pump. Most researchers just built the system and used it without conducting any research regarding its performance before start using it, and could not use it to its maximum potentials. However, there were some researchers from agricultural countries who conducted proper research on the system such as Shuaibu Ndache Mohammed (2007)., who conducted a research regarding the performance of the hydraulic ram pump by designing the system with the supply head of 1.5 m, and the pipes with 0.025 m diameter. The system could pump the water up to 2.87 m and the volume flowrate or discharge was 3.83×10^{-3} m^3/s with the performance rate of 57.3%. Phyo Minthan conducted a study on the performance of the hydraulic ram pump system with the supply head of 1.524 m, the pipes with 0.0762 m of diameter, and the boiler with 0.1524 m diameter with the height of 0.4572 m. The system could pump the water up to the level of 9.144 m high. It was also found that the water velocity that flowed into the system was 1.24×10^{-3} m^3/s and the volume flowrate or discharge was 1.05×10^{-3} m^3/s, which was calculated as the performance rate of 60%. The Development Technology Unit from a British university (DTU) conducted a research on the hydraulic ram pump with the supply head of 4 m, and the system could pump the water to the level of 16 m high. In Thailand, some researchers had conducted studies on the system to develop the performance of the system to higher level. and Sitthiho and coworkers conducted a study regarding the drain valve design to increase the performance of the hydraulic ram pump system (Sitthiho, Saneewong & Na-Ayuthaya et al. 2004). The usual valve of the system could be used to supply the water into the water tank, but it could not be modified to control the velocity of water flow. The study of "Adapted Foot Valve" was used to increase the velocity of water flow during the experiment. The supply head in the experiment was 2 m high, the velocity of water flow was 1,320 – 2,700 L/hrs, and the axis weight of the foot valve at the level of 30 cm. From the result of the experiment, it was found that the adapted foot valve could increase the velocity of water flow in the delivery head better than other kinds of foot valves in all height level, and the valve was more effective when the height was increased. Niyomwas and coworkers studied the performance of the same system with the supply head of 3 m (Niyomwas & Podkarat, 1998). The system could pump the water up to the height of 15 m, and the performance rate of the valve was 33.47 – 77.24%. When considered the ratio of the height of the delivery head to the supply head (H/h=5), the system that used the adapted foot valve had the performance rate of 67.57 – 89.98%. The result suggested that using the adapted foot valve had better performance.

According to the research of Banyat Niyomwas and coworker, the performance rate of the hydraulic ram pump could be calculated from Unsteady Bernoulli Equation) and Incompressible Fluid as shown in Eq. 2.1 (Niyomwas & Podkarat,1988);

$$\frac{P_1}{\rho}+\frac{V_1^2}{2}+gZ_1=\frac{P_2}{\rho}+\frac{V_2^2}{2}+gZ_2+\int_1^2\frac{\partial V}{\partial t}ds \qquad \text{(Eq. 2.1)}$$

P = pressure *V = velocity* *ρ = density*
t = time *s = distance* *g = gravity*
s = distance between point 1 to point 2 which was the surface of the water from water supply and the position before the water flows in the drain valve

The experiment on the performance of the prototype waterfall was conducted by installing the hydraulic ram pump in the waterfall then determine the performance of the pump by calculating the Mechanical Efficiency from Eq. 2.2. D' aubuisson's Efficiency could also be used to determine the efficiency of the hydraulic ram pump by using the Eq. 2.3 which calculated both kinetic and impact energy. The Rankine Efficiency was used to calculate the impact energy as described in Eq. 2.4. The performance rate in the form of height and the water velocity pumped into the water tank would be used to calculate the efficiencies.

Mechanical Efficiency: $\eta = \frac{P_{Hyd}}{P_{WF}} \times 100 \ (\%)$ (Eq. 2.2)

Waterfall power: $P_{WF} = \gamma Q h_{WF}$ (Watt)
Pump power: $P_{hyd} = \gamma Q h$ (Watt)

D'aubuisson's Efficiency: $\eta = \frac{q(H+h)}{(q+Q)h} \times 100 \ (\%)$ (Eq. 2.3)

Rankine Efficiency: $\eta = \frac{qH}{Qh} \times 100 \ (\%)$ (Eq. 2.4)

q = flowrate quantity inlet water (L/min)
Q = flowrate quantity of water loss (L/min)
h = the height of the supply head (m)
H = the height of the delivery head (m)

The work by Junprasert and coworkers (2003) showed the relation between the height of the supply head and the discharged pumped water. It was found that size of pumping system (25.4-101.6 mm inlet) affected the discharge water.

Larger inlet provided more discharge flowrate in the range of 2.5 - 8 L/min at supply head of 1 m. In addition, the supply head had high influence on the discharge. Higher volume of discharge could be achieved with higher supply head up to 20 L/min at supply head of 5 m. For the delivery head, with the largest inlet pump size of 101.6 mm could provide the delivery head up at 6 m from the supply head of 1 m. However, for inlet of 25.4 mm, the delivery head could only raise up to about 2.5 m. This meant that if the supply head was higher, the quantity of the water that could be pumped and delivery head would also be higher. In addition, if the pumping system was bigger, the quantity of the pumped water and delivery head would also be more.

From that experiment at the supply head of 2 m, it was found that the result of D' aubuisson's Efficiency equation was between 26.33 – 70.17% which is higher than the Rankine Efficiency equation which was 21.31 – 66.42%. The size of the pump that provided maximum performance was 101.6 milliliters, which had the result of D'aubuisson's Efficiency equation of 70.17% and the result of the Rankine Efficiency equation of 66.42%.

According to the information of R.I.D., if the quantity in the supply head was 210 L/min, the system would be able to pump up the water to the level of 11 m and the volume discharge was 19.8 L/min, and the average performance rate was 16.6% (Royal irrigation Department, 1981. P15-16). The research on designing and developing hydro power pump system with the water velocity in the supply head of 126 L/min would allow the system to pump up the water to the level of 11 m high with the volume flow rate or discharge of 22 L/min, and the average performance rate is 51.2% (NiranSuwanchai, WechaiChaicharernchat, 2001). When compared the result of both systems, it was found that the system with smaller supply head was able to pump up the water to higher level with less quantity of loss water, but the quantity of the water that could be used was less (Ekarat Junprasert, (2003). Therefore, the study suggested that the height level and the quantity of the water that was pumped up varied according to the quantity of the water and the height level of the supply head. However, the study was conducted with the supply head with the height level of 1 – 5 m, and did not provide information on the position withthe maximum performance rate.

Water Wheel Pump

In the past, the water wheel pump system was called by local farmers and villagers as "Luk" or "paddle pump" or "turbine pump." Its operating system was based on the principle of the velocity of the water that flows through the paddle of the system and transfers the momentum between the volume flowrate of the water and the paddle (Kummoon and Kongngen, 2009). The paddle was connected to the spindle of the system, and turned at linear speed of the water into the angular speed of the turbine. This mechanism spin the turbine with a certain torque speed. The turbine provided the suitable sinking level of the paddles and speed, and then used the generated speed and torque to power the mechanism of the system to pump water or to generate electricity. Luk was a turbine similar to Cross flow type turbine that operates with low speed. It had more advantage because it can be easily designed and built and it is also very easy to maintain. The system also provided high torque and was self-cleaning. the system did not need filtering mechanism for objects or animals in the water such as tree branches, fish, and etc. Another advantage of the system was that it needed no or low level of supply head. There were 3 types of the rotation of turbine system:

1. Overshot water wheel is a turbine system with high paddle. The name of this mechanism comes from the way the water falls into the paddles from high angle. The weight of the water inside will pull down the wheel until the water inside the paddle flows out. This mechanism would keep going and thus allowed the turbine to rotate continuously. This overshot water wheel provided low speed rate (less than 40 rpm) but with high torque due to the low speed of the system. Each paddle can received and carried high quantity of water, thus the torque. If the water capacity of each paddle could be indicated, it would be able to calculate the flow rate and the maximum speed.

2. Breast shot water wheel is the turbine system which the water flows into the water tray at the paddle at the mid-level of the turbine. The energy of the system came from the weight of the water in the paddles and the impact energy between the paddles and the water. This type of turbine system provided lower energy and performance rate than the first system. The characteristics of the system was similar to those of the overshot water wheel. The only difference was the position of the water that flowed into the paddle. In terms of construction, it required similar amount of the time and material as the previous one. In other word, this system was the same as the first one but it had been modified to makes it suitable for the water sources. However, the system did not provide an impressive result, because the angle of the paddles used with overshot water wheel could not be used with breast shot water wheel system.

3. Undershot water wheel is the system that water flows into the system

at low level or low angle. The energy of the system came from the impact energy of the water and the paddle. This type of low turbine system was the original type of the turbine systems. Nowadays, it had been developed and modified to use the energy from the weight of the water instead of solely relying on the impact energy. This undershot water wheel was the same system the researcher used for the experiment, because the researcher deemed that the system did not require high velocity of water flow and could be installed in every river and water sources. The system did not need any modification to be able to use with the water sources that run from high ground to lower ground such as rivers, canals, streams or irrigation system established by the Royal Irrigation Department for agricultural activities.

Figure 2.4 The development of old turbine system to Water Wheel system

Sources : G. AkhyarIbrahim C.H. et al., (2011).

All the mentioned water sources provide energy from its flow rate. Normally, the flowrate of these types of water sources are 0.5 – 2 m/s. There have been researchers who conducted studies on the flowrate energy. AkhyarIbrahim

(2011) conducted an experiment in Indonesia with water wheel pump made from hardwood with 300 cm diameter and 40 cm wide. It was installed in a flowing river and the wheel could bail the water up to 3 m high and transferred via bamboo tubes. Morgan and coworkers conducted a study at Henderson Research Center with spiral tube with the length of 20 m and 25 mm in diameter. The tubes were tied to a wheel with 2 m in diameter and it could pump 78 L/hr into the water tank (Morgan, 1984). After that, 4 m spiral tube were tested and it could deliver 4,752 L/hr in plain area, and deliver 3,697 L/hr to high ground with the height level of 8 m. The flow rate of the stream in the experiment was 1 m/s and the stream was 1.93 m wide. The wheel had 16 paddles, 600x600 mm, 3 spiral tubes with the 50 mm in diameter and the spin rate was 4.2 rpm. In their experiment, Hermans and coworkerbuilt a spiral tube of 50 m long with the diameter of 0.01905 m. He tied 20 spiral tubes to a 2 m size wheel, then installed and put ¼ of the wheel in the stream. The experiment result showed that the wheel could pump and deliver the water up to 16 meters (Hermans, 2014).

Economic Analysis on Hydro Power Pump

Ekarat Junprasert conducted performance study of the water pump to develop and modify the system to its highest capacity (Ekarat Junprasert et al., 2003). The factor that needed to be considered were the benefits that provided by the system was worth the investment. The analysis compared the expenses from using hydro power pump to other types of pump system that use electricity by including the cost of the construction of the hydro power pump. The analysis was based on only the supply head with the diameter of 25.4 mm and 19.05 mm tube as the preliminary principle of the analysis. The cost analysis consisted of 4,600 baht of materials and labor cost, the cost comparison between hydro power pump and electric pump, unit of electricity usage per month, and Capital Recovery and annual worth analysis. Annual worth analysis was a method used to evaluate a project which was favored by many analysts more than Present worth, because it was the method that used only one project life cycle which was an obvious advantage. Annual worth analysis could use with Equal Lived Alternatives or the project that was set to be Equal Lived. As for the project that had Perpetual Life, the annual worth can be easily calculated by multiply Present Worth with Rate of Return Value (Ekarat Junprasert et al., 2003). Rate of Return Value was the rate of the payment that needs to be paid back the loan or the revenue from the arrears of investments. Therefore, the final payment or the final sum of the received money could be used to calculate and set to zero (0) by the Rate of Return Value. The Rate of Return Value was presented as percentage (%) per period, for example; I = 10% per year, the positive rate of return value means the sum of money that the borrower pays back to the lender to liquidate the loan. The calculation to find the Rate of Return Value by using Present Worth analysis or Annual Worth analysis to set the Rate of Return Value of the money circulation of projects could be calculated by using either Present Worth analysis or Annual Worth analysis. Present Worth analysis can be used to calculate by setting the Present Worth of Disbursement equaled to the Present Worth of Revenue.