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Energy Efficiency Improvement for a Single Cylinder Agricultural Engine: An Application for Water Delivering by Agricultural Mixed-Flow Pump

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Abstract

In the current study, the water-delivering process which is a daily routine process for rice culturing has been analyzed and optimized to improve energy efficiency. An agricultural mixed-flow pump (Pa-ya-nak pump) powered by a single cylinder agricultural engine with v-belt power transmission was the considered system. Three main issues have been focused those are pump blade redesign, power transmission ratio optimization and belt tension optimization. The 10 inch (254 mm) diameter with 8 foot (2,438.4 mm) long agricultural mixed-flow pump was connected to two Kubota engines model RT140 and RT100 by v-belt power transmission. First, the inlet/outlet blade angles of the agricultural mixed-flow pump were re-designed from a manufacturer version and the prototype was tested at conventional pump speed from 800 to 1000 rpm at constant water head around 75 cm ($\pm$ 10 cm). The belt tension was adjusted to maintain best power transmission performance as that was investigated in our previous work. And the speed ratio between the single cylinder engine and pump was varied from 0.7, 0.9 and 1.1. The results showed that at optimum belt tension, the prototype pump has better specific fuel consumption which linearly depends on the pump speed. In addition the optimum speed ratio for the test engines RT140 is 1.1 and RT100 is 0.9.

Keywords*:* Energy efficiency, Agricultural mixed-flow pump, inlet/outlet blade angles, v-belt power transmission, power transmission ratio

1. Introduction

With traditional background and tropical rainforest climate, rice production in Thailand has the fifth largest amount of land under rice cultivation in the world and is the world second largest rice exporter. Therefore, rice production represents a significant portion of the Thai economy and labor force [1]. A key success of rice cultivation is water supply. It is recorded that central to lower-north region where has better water resource has higher yield (344-406 kg/m^2 or about 550-650 ton/rai in averaged of rainy season rice field and off-season rice field) in comparing to north-east region (219 kg/m^2 or about 350 ton/rai) [2]. Therefore, a routine process during rice growth is water delivering which must be done once for three days within 4 months of rice cultivation period. To cover this burden, Thai's rice planters usually use the agricultural mixed-flow pump which is specifically adapted and named as Pra-ya-nak or Thep-pa-rit pump, shown in Fig. 1.

(a) (b)

Fig. 1 Agricultural mixed-flow pump
(a) Overall pump body (b) Pump blade

The agricultural mixed-flow pump, used in Thailand was adapted from its original version since half a decade [3] by Mom Rajawongse Thepparit Devakul since 1959. It has performance match with rice cultivation, i.e., low pumping head (1-4 meter) appropriate with regular geography of rice plantation and high flow rate (1,500-3,000 liter/min).

The pump is usually driven with the single-cylinder agricultural diesel engine by using V-belt power transmission. According to the record from National Statistical Office of Thailand [4], shown in Table 1, the single-cylinder agricultural diesel engine is widely owned by farmers and can be applied in either way by couple with walking tractors or individual use as multi-purpose powertrain, i.e. electric generator, drum seeder and also for water delivering duty. In addition, the farmers select the V-belt power transmission because it is more flexible and easier to use than other devices such as chain and gears. In addition, the belt is also a cost effective power transmission with a minimum of maintenance [5]. The efficiency of transmission is relative high ranging between 90 to 98 percent [6].

Table. 1 Record of agricultural machineries in Thailand [4]

	Total	Own by farmer
4 wheel Tractors		
-<15 HP	258,247	21.21%
-18-50 HP	599,248	18.45%
->15 HP	804,203	10.50%
Walking tractors	3,647,361	67.67%
Centrifugal, Pra-ya-nak pump (Use engines)	1,615,692	82.50%
Pesticide Spraying machine	1,020,369	67.59%
Drum seeder machines		
-Use their own engine to drive	58,176	35.35%
-Use with a walking tractor	111,384	58.16%
-Use with a 4 wheel tractor	77,825	25.18%
Harvesting machines		
-Sugarcane cutting machines	51,426	3.82%
-Rice threshing machines	1,456,542	1.86%
Seed massaging or cracking machines		
-Rice and cereal threshing machines	1,455,326	2.13%
-Corn cracking machines	203,015	1.76%
-Rice and cereal winnowing machines	54,008	12.96%
Rice polishing machines	2,642,701	1.68%
Total	15,054,855	-

Concerning to this arrangement for water pump in rice cultivation process, this system is composed from several devices i.e. mechanical power generation (single cylinder diesel engine), power transmission (v-belt and pulley), mixed flow agricultural pump, etc., the system must be carefully maintained to achieve best energy efficiency. However, the above devices are often used with careless, less-understanding users. Therefore, the aim of this study is to improve energy efficiency by focusing on three issues.

First the pump blade which was designed since 50 years ago and has been devolving upon a few pump manufacturer generations was redesigned. The engine efficiency was optimized with hydraulic load of mixed flow pump by varying speed ratio between engine and pump shaft. Finally, the belt tension was adjusted, follow to our previous work [7] which focused on v-belt and pulley power transmission system. 2 kg weight was loaded at the center of engine/pump pulley length. Then belt tension was adjusted until deflection of belt equaled to 1/64 of engine/pump pulley length to ensure best power transmission as concluded in previous work. The experimental test was performed to analyze energy efficiency improvement by those three focused points.

2. Methodology

Fig. 2 shows the experimental apparatus of water pump system. The agricultural diesel single cylinder engine modelled Kubota (RT140 or RT100) were placed near a canal side which has small water level variation. So, the water pump system was operated at constant water head (H, m) around 75 cm (±10 cm). V-belt/pulley power transmission was used to couple the engine with the mixed-flow pump. Engine and pump was pushed out of another with F_a (in Fig. 2) to control belt tension, τ in Fig. 2 equal to that is recommended in our previous work [7]. Water flow rate (Q, m^3/s) was measured downstream of the pump by an orifice meter which was designed according to ISO-5167 standard of fluid-flow measurement [8]. Therefore the hydraulic power (P_H, kW), delivered by pump system can be calculated by equation (1).

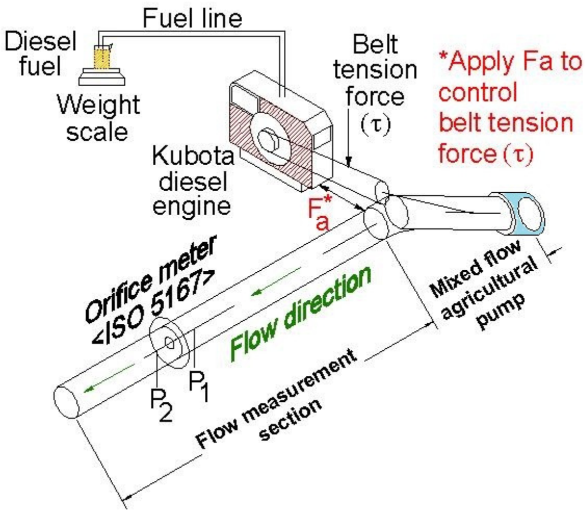


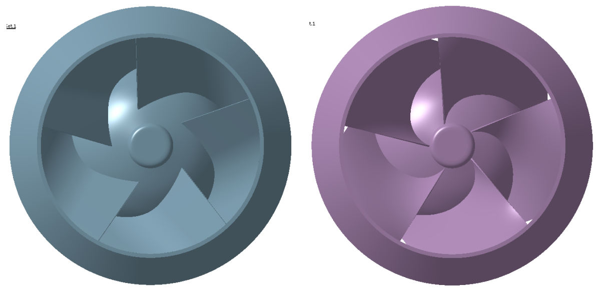
Fig. 2 Schematic diagram of experimental apparatus

$$P_H = \frac{\rho g Q H}{1,000} \quad (1)$$

$$sfc = \frac{\dot{m}_f}{P_H} \cdot \frac{3,600}{1,000} \quad (2)$$

where ρ is fluid density (kg/m^3) and g earth gravitation acceleration (m/s^2). In contrary, the engine generated mechanical work output by consuming diesel fuel. Diesel fuel flow rate ($\dot{m}_f$, g/s) was measured by a weight scale and a timer. Then the energy efficiency will be measured as the specific fuel consumption (SFC, kg/kW-hr), determined by equation (2).

2.1 Redesign of Mixed Flow Pump



(a) (b)

Fig. 3 Sketch of the considered mixed flow pumps (a) Manufacturer pump (b) Prototype pump

The sketch of original pump and prototype pump are shown in Fig. 3. Currently, the prototype of mixed flow pump which was modified from the original manufacturer's pump is in a process of patent licensing. So, the detailed design of the prototype pump is still classified at this moment.

2.2 Test Condition

Table. 2 Test conditions

Tested pumps	Prototype and Manufacturer
Pump speed (rpm)	800, 850, 900, 950 and 1,000
Ideal speed ratio (engine pulley size, inch)	1:0.7 (3.5") 1:0.9 (4.5") and 1:1.1 (5.5")
Pump pulley size (inch)	5"
Test engines	Kubota RT140 and RT100
System head (m)	80 $\pm$ 10 cm
Test fuel	Diesel B5

The test conditions are summarized in the Table 2. The test condition was managed to achieve 3 objectives of this work. First, the specific fuel consumption (SFC) of the new design prototype pump was measured and compared to the manufacturer's pump. Then the effect of speed ratio was combined to improve energy efficiency by matching hydraulic load with engine performance. In this case, the engine pulley was changed from 88.9, 114.3 and 139.7 mm (3.5, 4.5 and 5.5 inch) while the pump pulley was fixed at 127 mm. The ideal speed ratio was defined in this work, to generally name the test condition and determined from ratio of pump/engine pulley size. It was varied from 1:0.7, 1:0.9 and 1:1.1. Finally, the Kubota engine modeled RT140 was changed to another model RT100 to increase more details on engine-to-load matching. The engine specifications are shown in Table 3.

Table 3 Engine specifications [9]

	Kubota RT140	Kubota RT100
Engine arrangement	Single cylinder horizontal	
Combustion	Diesel direct injection	
Bore x Stroke (mm)	97 x 96	88 x 90
Displacement Volume (cm^3)	709	547
$Power_{max}$@speed (kW@RPM)	10.30@2400	7.4@2400
Torquemax@speed (kg-m@RPM)	5.0@1600	3.4@1600

3. Results and Discussion

3.1 Recommended Belt Tension

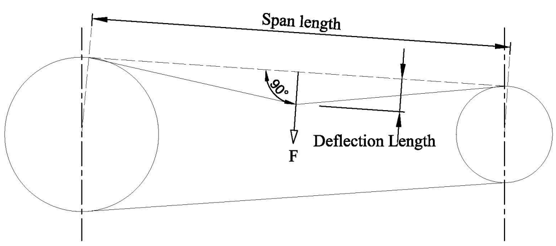
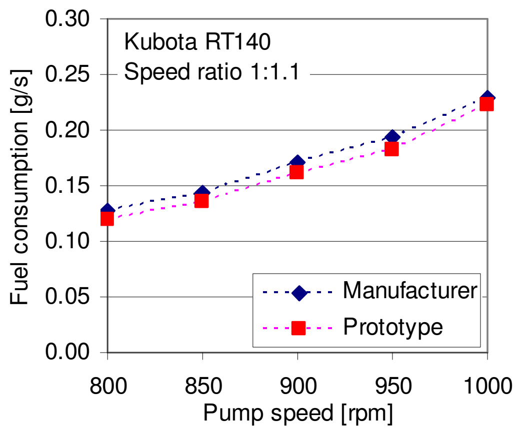


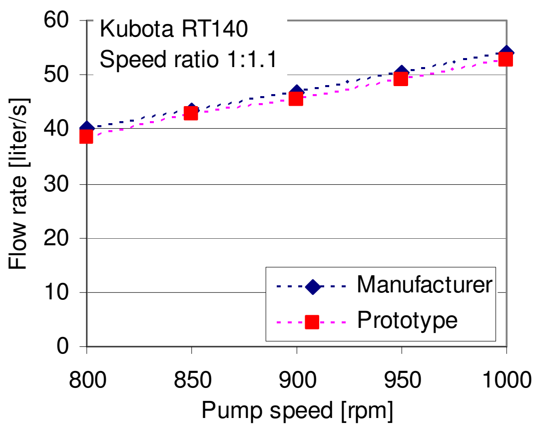
Fig. 4 Definition of force deflection method [7]

Referring to our previous work, the belt tension must be optimized to obtain lowest power transmission loss. The Fig. 4 shows how to set the belt tension with the deflection method. The deflection force (F) is defined as the force applied, until the deflection length reach 1/64 of span length. As it is found in our previous work, the deflection force (F) is set at 2 kg for all test condition [7].

3.2 Effects of Redesigned Pump Blade



(a)



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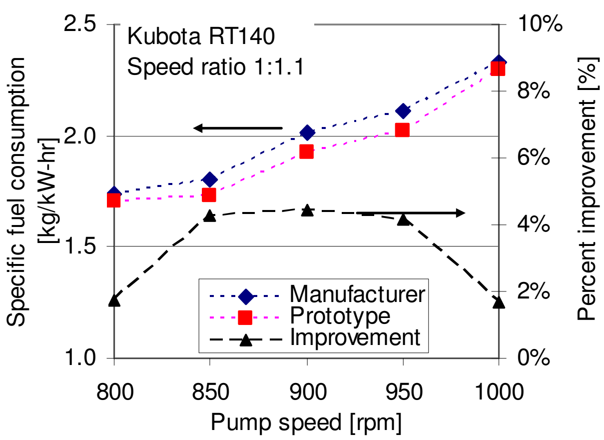


(c)

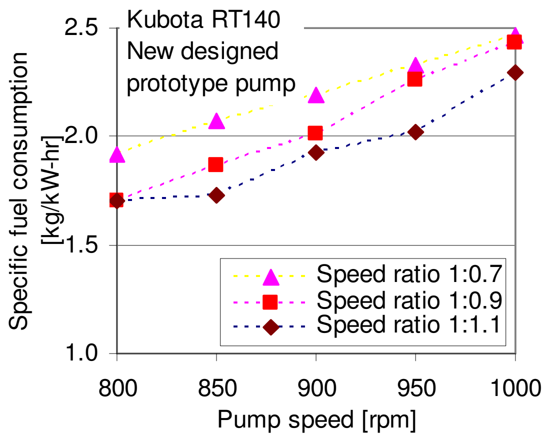
Fig. 5 Comparison between prototype and original pump design (a) Fuel consumption (b) Flow rate (c) Specific fuel consumption

Fig. 5 compares fuel consumption ($\dot{m}_f$, Fig. 5.a), flow rate (Q, Fig. 5.b) and specific fuel consumption (SFC, Fig. 5.c) between the new designed prototype pump and the original manufacturer's pump in the condition of speed ratio 1:1.1 (engine pulley 5.5 inch). Firstly, the results show that for each setting up, $\dot{m}_f$, Q and SFC linearly depend on pump speed.

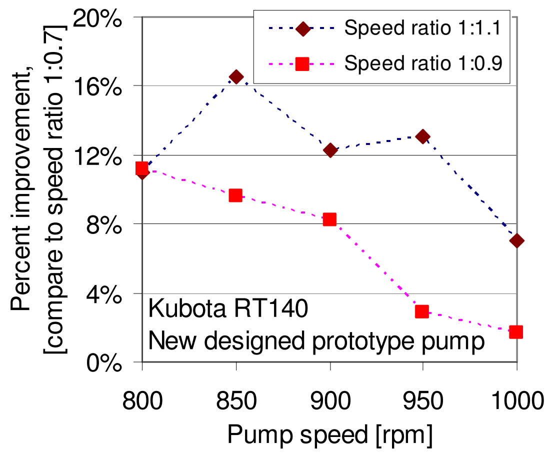
The results show that the new designed prototype pump has lower $\dot{m}_f$ but also provides smaller Q for each pump speed. However, the SFC of the prototype is lower than the manufacturer's pump. So, it can speak that the prototype pump can deliver more water if using similar fuel rate. The results show that prototype pump provides highest energy efficiency improvement of 4.43% at 900 rpm of pump speed and speed ratio of 1:1.1.

3.3 Effects of Speed Ratio Selection

The effects of speed ratio were analyzed for two engines with different sizes, Kubota model RT140 and RT100 (maximum power 10.3kW@2400 and 7.4@2400). Fig. 6 and 7 show the results of specific fuel consumption (SFC) when using various speed ratios from high to low: 1:0.7, 1:0.9 and 1:1.1 for RT140 and RT100 engines, as respectively. The results of SFC are showed with two methods: (a) show the SFC results and (b) show the percentage of SFC changing in the relative with results of speed ratio 1:0.7. Note that, the canal water level was a little averaged higher for RT100 test that result in lower SFC, in a comparison between Fig. 6.a and 7.a.



(a)



(b)

Fig. 6 Effects of speed ratio with RT140 engine (a) Specific fuel consumption (b) Percentage of SFC improvement

It is cleared in Fig. 6.a for the bigger RT140 engine, when speed ratio decreases from 1:0.7 to 1:0.9 and 1:1.1, the specific fuel consumption decreases in each step. The maximum SFC improvement is 11.18% at pump speed 800 rpm for speed ratio reducing to 1:0.9 and 16.50% at pump speed 850 rpm for speed ratio reducing to 1:1.1. The effects of speed ratio on SFC improvement trend to decrease with increasing of pump speed. The smaller engine RT100 shows the similar trend when changing to 1:0.9.

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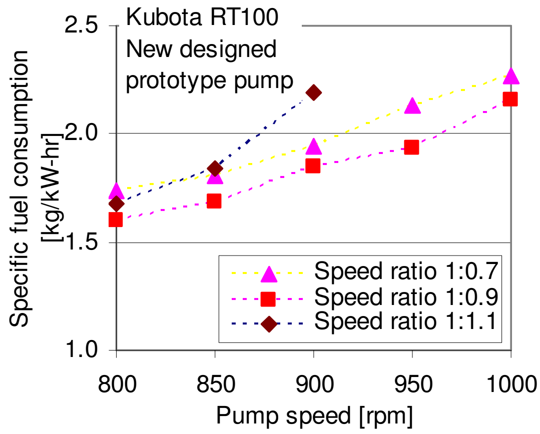
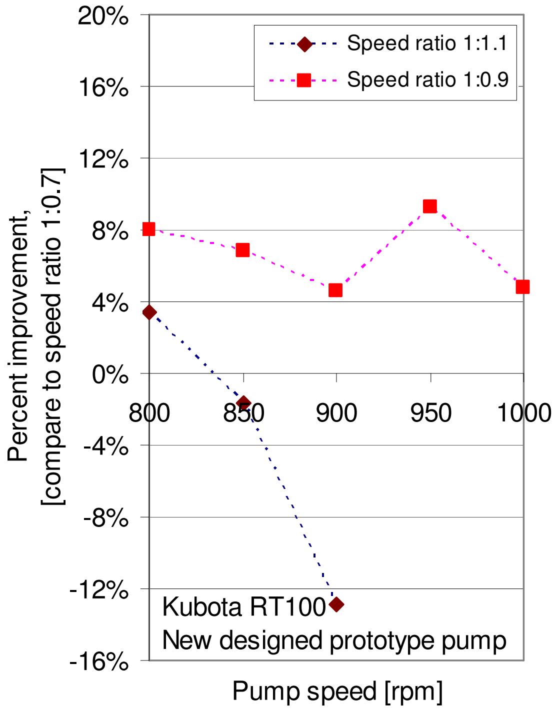


(a)



(b)

Fig. 7 Effects of speed ratio with RT100 engine (a) Specific fuel consumption (b) Percentage of SFC improvement

The maximum SFC improvement is 9.23% at pump speed 950 rpm. However, when the speed ratio changes to 1:1.1 the specific fuel consumption increases. It was found in experiment that the engine release a lot of black smoke from the tail pipe and the pump speed cannot be increased. It can be noted that for equivalent power output, the low speed range operation with low speed ratio can provide better SFC. However the engine cannot be operated in the region that is out of its operating range. The Fig. 8 shows the results of SFC plotted with measured engine speed.

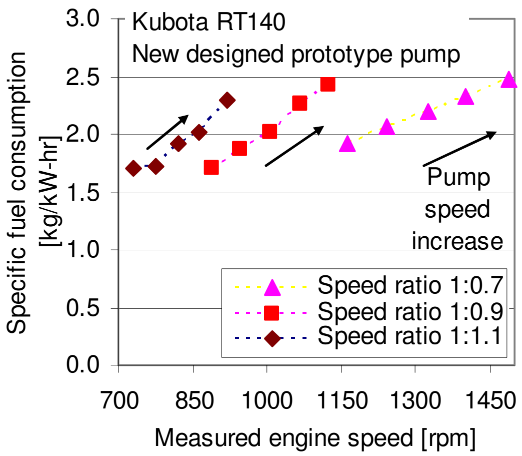


Fig. 8 Relationship between SFC and measured engine speed

4. Conclusion

The potentials to improve energy efficiency for the water delivering process were investigated in this work. Three issues of the considered pump system were focused and can be summarized as follows:

- A method to maintain best belt tension has been clarified follows our previous work [7].
- The prototype blade can provide higher specific fuel consumption more than 4% for the pump speed between 850 and 950 rpm.
- Specific fuel consumption can be much improved by matching requirement load with engine performance with optimized speed ratio.

5. Acknowledgement

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