COMPARISON OF TWO MECHANICAL WINDMILLS FOR PUMPING WATER

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ABSTRACT

A comparison of two mechanical wind pumping systems was carried out to determine windmill performance at different water depths. A 2.44 m (8 ft) rotor diameter windmill with 15 vanes, and a 4.88 m (16 ft) rotor diameter windmill with 32 delta wing vanes, were compared. The smaller windmill had vanes that filled 90% of the rotor area while the vanes on the larger one filled 41% of the rotor area. The smaller unit used a gearbox and the larger one used a pump jack style with a counter weighted shaft. Results from this study showed that both windmills started pumping at about the same wind speed (2.5 and 3.5 m/s), but the larger rotor operated at 6 to 8 strokes per minute faster than the smaller system when wind speeds were between 4 and 10 m/s. Although both windmills were fitted with the same size and style of pump, the larger rotor pumped more water because it had more stokes per unit of time. The delta wing rotor averaged 14,874 L/day compared to 10,974 L/day for the traditionally designed rotor. However, one must consider the difference in rotor diameters, total weight, cost and the efficiency of the two units. The larger rotor had a peak efficiency of 6.5% compared to 10.5% for the smaller rotor. The 35% more water pumped required twice as much rotor diameter.

INTRODUCTION

Over 1000 known windmill manufacturers have produced water-pumping windmills in the United States through the years with many of these manufacturers going out of the business by 1920 (1). Windmills were improved by using all steel rotors and enclosing the gears in an oil bath. Except for these two modifications, little has changed on these windmills since the early 1900's. By the 1970's, only a handful of manufacturers remained and they produced only a few machines per year. Similarly, the pumps have not changed significantly. Urethane cups have replaced leather cups in the single-acting piston pump to provide longer life. Fiberglass pump rods have replaced many wooden rods in recent years; however, galvanized steel pipe is still used for the drop pipe.

New interests have spurred a resurgence of manufacturing of mechanical windmills. Several new companies have introduced machines for the remote water pumping market. Most mechanical windmills are used for livestock water pumping in remote areas where no electric grid power is available or it is too expensive to extend the grid to the water supply. Many of the new systems are designed with counterbalancing or without a gearbox. A main objective of these new designs is to reduce the starting torque.

Traditional multibladed windmills start pumping water at a wind speed of approximately 3.5 m/s and reach a peak flow at a wind speed of 9 to 10 m/s, depending on the furling spring tension (3). The furling spring tension controls the maximum pump speed, thus the volume of water pumped. Manufacturers recommend that the pump speed not exceed 35 strokes/minute.

The two windmills compared in this study were erected at the USDA-Conservation and Production Research Laboratory, Bushland, TX by the USDA-Agricultural Research Service for use in wind-powered water pumping experiments. Every effort was made to make the comparison as equal as possible. Identical pumps, pump rods, and drop pipes were used as well as having both windmills erected on towers of equal height.

DESCRIPTION OF EQUIPMENT

The windmills were located 100 m apart and were operated at the same pumping lift and with identical pumps. Both units were mounted on 10-m steel towers. A single data logger was used to record wind speed from a 10 m meteorological tower located near the windmills. Stroke speed, water flow rate, and discharge pressure from each windmill pump were also recorded by this data logger. All data were sampled at a rate of one Hz and averaged for one minute. The one minute averages were recorded for later analysis by the method of bins. All data were analyzed using a 486 personal computer and SAS/STAT[1] (SAS Institute, Inc.) software.

Dempster Model 12A

The windmill was manufactured by Dempster Industries[1], Inc., Beatrice, Nebraska. Dempster has been manufacturing windmills since 1878 and introduced a self-oiling unit in 1931. The main change since the 1930's has been the replacement of the babbitt bearings with Garfil sleeve bearings (1). The Dempster windmill has a rotor diameter of 2.44 m with 15 blades and a pump stroke length of 180 mm. This horizontal-axis windmill was back-geared with a gear ratio of 3.3 to 1. All gears operated through an oil reservoir for lubrication. For overspeed control, the rotor turns sideways into the wind which is called furling. The wind speed at which furling begins can be adjusted by changing the spring tension between the gearbox and tail vane. The maximum pump speed is also adjusted by changing the spring tension acting on the tail vane. The installation manual reads: "The speed of the windmill is regulated by hooking the end of the regulating spring in the various holes provided for this purpose in the vane stem horizontal flange. There are five holes. Increase tension of the spring to increase speed of the wheel. Decrease tension of spring to decrease speed of the wheel. Approximate maximum speed is 32 strokes of pump rod per minute." (2).

Dutch Delta 16

The windmill was manufactured by Dutch Industries[1], Regina, Saskatchewan. Dutch Industries has been manufacturing this wind turbine since 1990 and has established several dealers in the US Great Plains region. This horizontal-axis windmill has a rotor diameter of

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[1] The mention of manufacturer's names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

4.88 m with 32 delta wing vanes. The delta wing vanes are designed to produce high torque at low wind speeds and provide rotor speed control at high wind speeds. The windmill used an oil field pump jack style direct drive rather than a geared transmission. The lifting arm is countered balanced to reduce the starting torque at low wind speeds. The stroke length of the pitman arm was 165 mm. The wind turbine furls horizontally when wind speeds exceed 10 m/s. Additional details of this design are described by Kentfield and Cruson (4).

Pumps

Identical single-acting piston pumps, 70-mm in diameter, were used on each windmill. The pump barrels were constructed of brass and polished to insure a proper fit with the sealing cups. The valves were also constructed of brass and each was fitted with new urethane cups at the beginning of the study. Pumping lifts were set at 30 and 45 m during the tests. The single-acting piston pump which is used with mechanical windmills had a fixed-stroke length and required constant operating torque from the windmill rotor.

RESULTS

The first comparison made was to determine the pump speed at the furling adjustments suggested by the manufacturers. The Dempster uses a spring to provide the appropriate tension between the tail vane and rotor head. It was adjusted so that the maximum pump speed would be 32 stokes/min as shown in Figure 1. The maximum stroke speed occurred at approximately 10 m/s wind speed. The Dutch Delta can not be adjusted for maximum puping speed. The adjustments on the tail are for cosmetic purposes and have no influence operation or pump speed. The maximum stroke speed was measured at a wind speed of 9 m/s and the value was 38 strokes/min (Figure 1). The Dutch Delta operated at a faster stroke speed than did the Dempster when winds speeds were between 2 and 10 m/s.

With a fixed pump stroke length and pump diameter, stroke speed of the single-acting piston pump is the only variable to change the rate of water pumped. The flow rate or volume of water pumped is linearly proportional to the pump speed. A comparison of the flow rate as a function of stroke speed is shown in Figure 2 for the Dempster and Dutch Delta windmills pumping against a 45 m lift. The Dutch Delta pumps slightly less water than the Dempster for the same stroke speed because its stroke length is 165 mm compared to 180 mm for the Dempster. These data clearly show that the pumps used in this study performed identically and any differences determined were due to the wind rotors and/or gearing; not the pumps.

The water flow rates for the two windmills are shown in Figure 3. The flow rates provided curves that are shaped similar to the stroke speed curves. The Dutch Delta pumped more water between the wind speeds of 3 to 10 m/s, but pumped less water at high wind speeds. The Dutch Delta started pumping at a wind speed of 2.5 m/s compared to a wind speed of 3.5 m/s for the Dempster. Earlier testing has shown that most mechanical windmills manufactured with the back gearing system start pumping at about 3.5 m/s (3). Considering the volume of water pumped and the reduction of only 1 m/s in starting wind speed, I doubt that the benefits of the lower starting wind speed is significant. Other pumping conditions where the pumping volume is greater or the lift is lower might make this an attractive feature of the Dutch Delta.

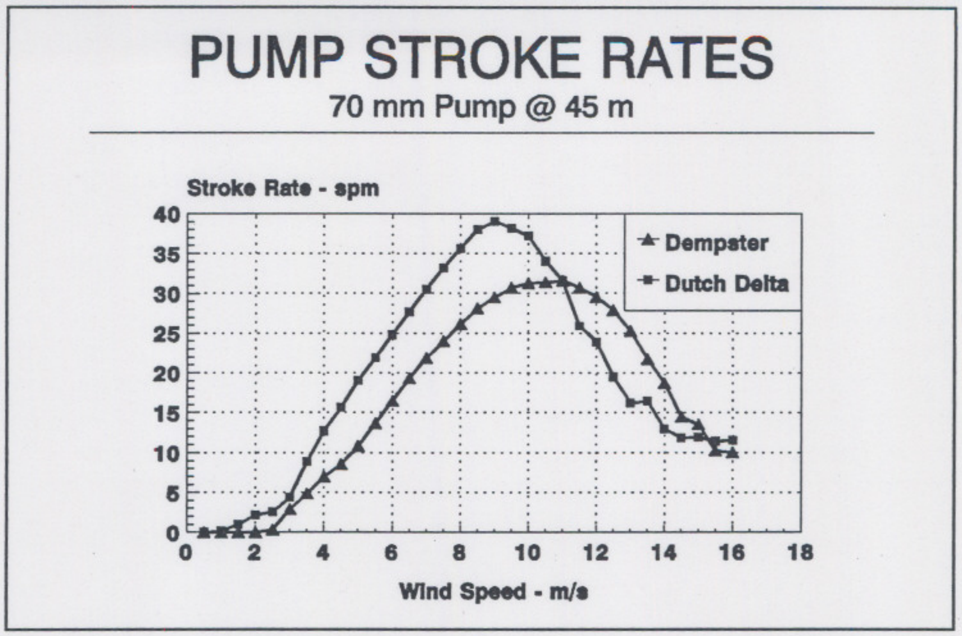

Figure 1. Comparison of pump speed for Dutch Delta and Dempster windmills with furling set at manufacturer's specifications and a pumping head of 45 m.

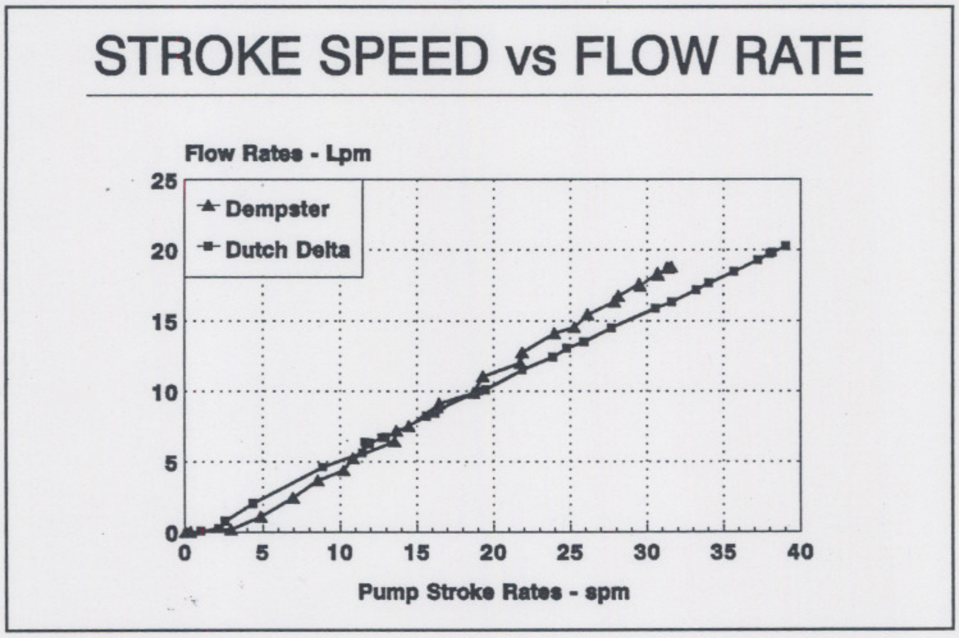

Figure 2. Comparison of the flow rates at various stroke speeds for Dutch Delta and Dempster windmills. Pumping head was 45 m.

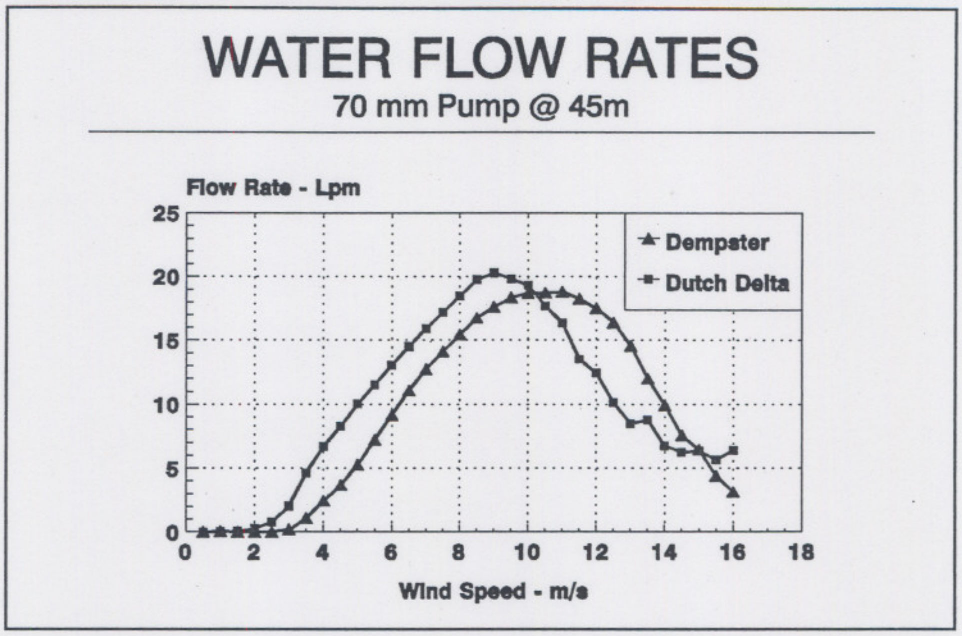

Figure 3. Comparison of water flow rates from Dutch Delta and Dempster windmills pumping against a 45 m head.

Because the wind speed is continuously changing and thus the rate of water being pumped changes with wind speed, the average daily volume of water pumped becomes an important consideration. A landowner must compare or match the average daily volume of water pumped to his average daily consumption. The average daily volume of water pumped was determined for each pumping system by using the flow curves in Figure 3 and ten years of hourly wind speed data. Figure 4 shows the average daily volume of water pumped for each month for the two units. The Dutch Delta out-pumped the Dempster each month and the difference was greater during the low wind speed months (August & September) than during the high wind speed months (March & April). The Dutch Delta averaged 14,874 L/day while the Dempster averaged 10,974 L/day when a 70 mm pump was used and the pumping head was 45 m. About 35% more water can be pumped with the Dutch Delta.

Overall efficiency was determined by using the water power (power required to lift the water) compared to the wind power (power in the free wind flow). As shown in Figure 5, the Dempster had a peak overall efficiency of 10.5% at a 6.0 m/s wind speed. The peak efficiency does not occur at the point of maximum pumping, but at the point of maximum torque; usually about 35-40% of maximum flow. The higher solidity (more blade area filled with blades) in the Dempster wheel probably provided for additional torque which enables the rotor to turn faster at this moderate wind speed, thus providing more water and a higher efficiency. The Dutch Delta had a peak overall efficiency of 6.5% at a wind speed of 4 m/s. The delta wing rotor concept produced its highest torque at a lower wind speed, thus the peak efficiency occurred at a lower wind speed. The Dutch Delta does not perform at a high efficiency because much of the rotor area is open and does not extract usable power.

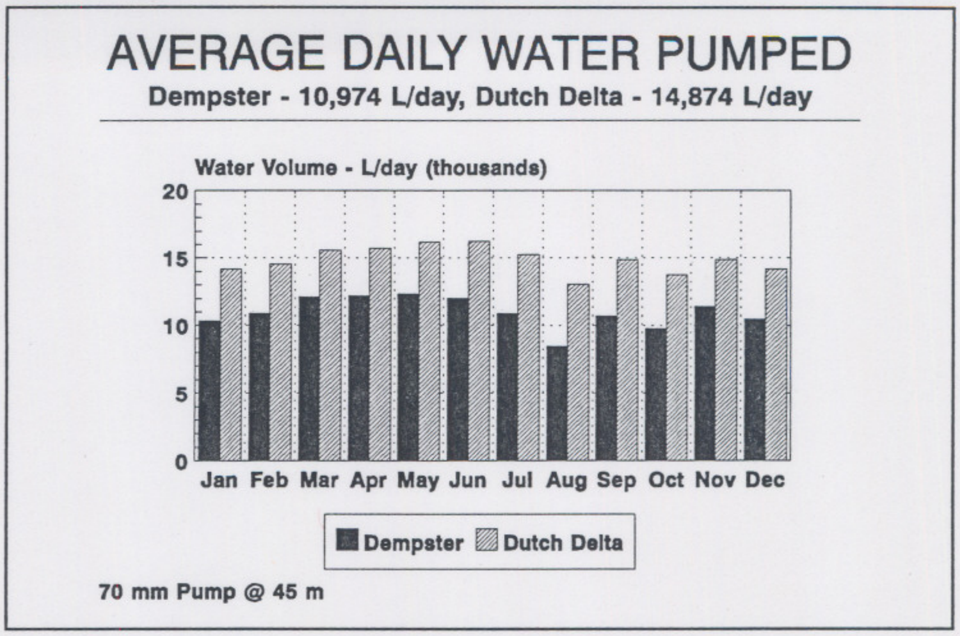

Figure 4. Comparison of the average daily water volume pumped during each month for the Dutch Delta and Dempster windmills.

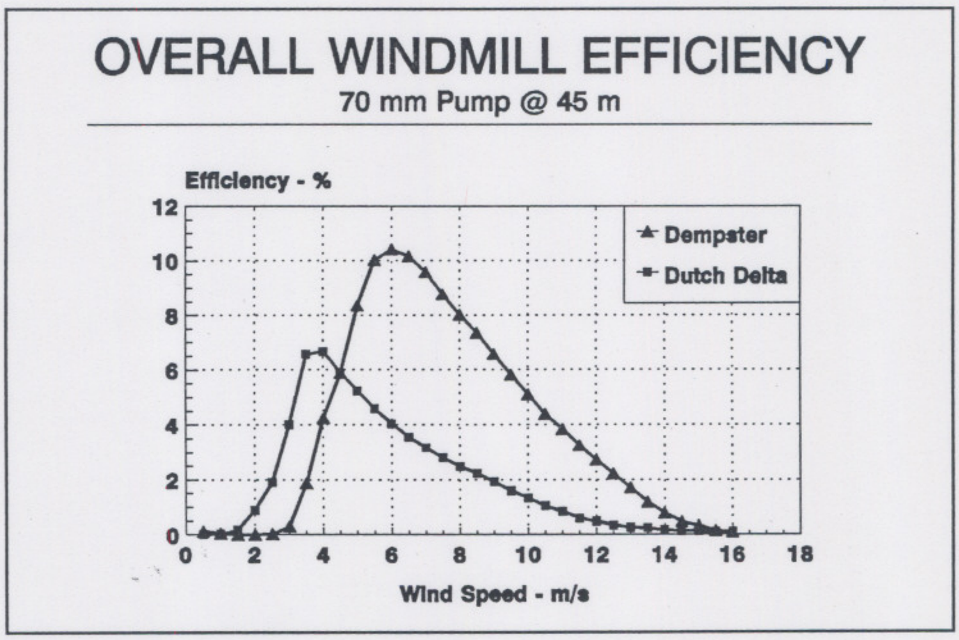

Figure 5. Comparison of overall efficiency for the Dutch Delta and Dempster windmills when pumping against a 45 m head.

CONCLUSIONS

Two multibladed, mechanical water-pumping windmills were compared in side-by-side tests by the USDA-Agricultural Research Service, Bushland, TX. The two units were quite different in rotor design and the method of transferring the shaft power to reciprocating motion. The Dempster windmill was of the traditional design with 15 vanes and back-geared system. The Dutch Delta used a delta wing design which had 32 small vanes around a 4.88 m diameter circle and had a counter-balanced pump jack style arrangement to change the rotary motion into reciprocating motion. Because of the delta wing design, the Dutch Delta required a larger rotor area to produce the same amount of power. The Dutch Delta with a rotor diameter twice as large as the Dempster started pumping in wind speed of 2.5 m/s as compared to the 3.5 m/s required for the Dempster. At a pumping head of 45 m, the Dutch Delta pumped about 35% more water than the Dempster. The peak overall efficiency of the Dempster was measured at 10.5% as compared to 6.5% for the Dutch Delta. The peak efficiency occurred at wind speeds of 4 to 6 m/s when the windmills were turning slowly and the torque was high. The efficiency was low for the Dutch Delta because the delta wing design has a large open space in the center of the rotor that does not contribute power to the rotor. It is believe that the maintenance of the Dutch Delta will be high because of the large number of small bolts on the rotor and the number of bearings to keep greased.

ACKNOWLEDGMENTS

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