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SERI/TP-1980

EVALUATION OF PUMP EFFICIENCIES AND OPERATING COSTS FOR SDHW SYSTEMS

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ABSTRACT

Pumps for solar domestic hot water (SDHW) systems are often assumed to operate efficiently and inexpensively since they are relatively small. However, analysis and testing of these pumps at the Solar Energy Research Institute (SERI) showed that these pumps operate at low efficiencies and that the operating costs can be substantial for certain types of SDHW configurations and control strategies. Possible solutions for this problem are presented.

1. INTRODUCTION

Four typical SDHW system pumps were tested at SERI to determine their head, power, and overall efficiencies as a function of flowrate. The test set-up and results are presented in detail in Reference 1. The initial instrumentation included Viatran absolute and differential pressure transducers, a Cox turbine flowmeter, a General Electric ammeter, a Fluke multimeter, an ERA wattmeter, and a Hewlett Packard 3054 Data Logger that collected data and provided the results in tabular and graphical form. The test results deviated from the expected results several times more than the uncertainty of the instrumentation. An inspection and calibration of the instrumentation led to the replacement of the pressure transducers with pressure gauges.

2. PUMP PERFORMANCE

The published and experimental head-flow curves for the Taco 009 pump were presented in Figure 1 and for the Grundfos UPS 20-42 three speed pump in Figure 2. In general, these pumps met or exceeded the published head versus flow performance. The power factor of the pumps was also determined by measuring the voltage, current, and real power of the pump. The results are presented in Table 1.

The power factor was determined to see if it was close to unity, as is often assumed. Power consumption for a pump is often calculated by measuring the current to the motor (or using the published current rating) and multiplying by the rated constant line voltage, thereby assuming a power factor equal to unity.

The overall efficiency of the motor is defined as the hydraulic power provided by the pump (flow times head) divided by the electric power to the pump. This denotes how efficiently the pump (including the pump motor) uses the electricity to move the water. The results for the Taco and Grundfos pumps are shown in Table 2 and indicate efficiencies below 16% for the flowrates tested.

Since the measured head and flow data points fall close to the published head versus flow curve, the measured efficiency is very close to the efficiency that would be calculated from the published curve. However, pump efficiencies are often assumed to be much higher, on the order of 35% to 90%. These types of efficiencies are typical for larger pumps but not for these small pumps.

Published pump efficiencies for SDHW pumps are on the order of 35%. This is the efficiency of the mechanical components of the pump alone (impeller, shaft, bearings) and excludes the pump motor. It is the hydraulic power divided by the shaft power. The designer and user should be concerned with the overall efficiency of a pump and not just the pump mechanical efficiency.

Table 1
Pump Power Factors

Flowrate $(\ell \cdot m^{-1})$	Voltage[a] x Current (Volt·Amps)	Wattmeter[b] (Watts)	Power Factor	Uncertainty[c]
Taco 009:				
20.1	147.6	129.2	0.875	±0.067
17.4	146.4	127.8	0.873	
17.0	147.6	127.3	0.862	
11.0	138.9	120.9	0.871	
4.5	136.5	113.9	0.834	
2.3	131.5	111.4	0.847	
0	130.2	108.1	0.830	±0.072
Grundfos UPS 20-42:				
Speed III				
13.6	96.9	96.4	0.995	±0.39
6.8	94.5	94.1	0.995	
0	92.1	91.2	0.991	
Speed II				
11.4	78.3	76.3	0.974	±0.047
5.9	77.1	74.3	0.963	
0	73.4	71.4	0.973	
Speed I				
8.3	57.3	54.3	0.948	±0.062
4.5	56.0	53.3	0.951	
0	54.8	51.8	0.946	±0.065

[a] ±1.1 V; ±0.09 A for Taco; ±0.03 A for Grundfos

[b] ±0.25% of reading

[c] Root mean square uncertainty

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Table 2
Measured Pump Efficiencies

Pump	Flowrate ($\ell \cdot m^{-1}$)	Head (kPa)	Power (Watts)	Overall Efficiency (%)
Taco 009:				
	20.1	60.0	129.2	15.5
	71.0	68.9	127.3	15.4
	11.0	79.3	120.9	12.0
	4.5	86.9	113.9	5.8
	2.3	81.3	111.4	2.8
	0	82.0	108.1	0.0
Grundfos UPS 20-42:				
Speed III	13.6	34.5	95.4	8.1
	6.8	39.3	94.1	4.7
	0	42.0	91.2	0.0
Speed II	11.4	27.6	76.3	6.8
	5.9	31.7	74.3	4.0
	0	33.8	71.4	0.0
Speed I	8.3	19.3	54.3	4.9
	4.5	19.3	53.3	2.7
	0	23.4	51.8	0.0

3. OPERATING COSTS

The operating cost for solar domestic hot water systems is often assumed to be negligible. The actual hydraulic power required is small, but with very low pump efficiencies, the required electric input may be large. The calculation of the operating cost is straightforward and may be done in two ways. If the pump size is known, the pump motor electrical rating is multiplied by the expected number of operating hours and the cost of energy. The results of such a calculation are shown in Table 3 for various pump sizes and costs of energy.

Table 3
Operating Costs of SDHW Pumps
(assuming operation of 2500 $hrs \cdot yr^{-1}$)

Nominal Pump Rating	Annual Operating Cost	
	\$.05/kWh	\$.10/kWh
10W	\$ 1.25	\$ 2.50
40W	5.00	10.00
70W	8.75	17.50
100W	12.50	25.00
150W	18.75	37.50
200W	25.00	50.00
250W	31.25	62.50

If the pump size is not known, but the design pressure drop and flowrate are known, then a pump size can be estimated by dividing the hydraulic power, in watts, (head times flow) by an assumed pump efficiency. The previous procedure using operating hours and the cost of energy can then be used.

Reference 2 tested five SDHW systems in New York State and measured parasitic energy (pump, controller, and valves) between 500 and 1,000 kWh per year, which is equivalent to a 200W to 400W pump operating 2500 hours a year. Reference 3 monitored 34 pumped systems in Oregon State which had measured parasitic energy between 73 and 511 kWh per year (excluding a faulty system using 1314 kWh per year) with a median value of 146 kWh per year. The median value is equivalent to a 65W pump operating 2500 hours per year, assuming the parasitic energy required to operate the automatic valves, if any, and the control system is negligible. This assumption is valid because only five of these systems had drain valves.

4. EFFECT OF SYSTEM CONFIGURATION AND CONTROL

Some systems have oversized pumps which result in a decrease in savings due to an increase in operating costs. Others have unnecessary pressure drops dictating the use of larger pumps.

However, some systems, such as drainback systems, require larger pumps, at least whenever the pump starts. A drainback system is usually an indirect system utilizing a heat exchanger between the collector loop and potable water supply. Freeze protection is provided by draining water from the collectors and exposed piping into the solar storage tank or a drainback reservoir whenever the collector loop pump stops.

Whenever the collector loop pump starts, it must raise the water against gravity (static head) and then either develop a syphon return (eliminating the static head) or permit the water to freefall (open drop) through the downcomer. In an open drop return, the pump continues to pump against the static head. If a syphon-return system is used, the head decreases and the flowrate increases. This can be seen by examining the head versus flow curves shown in Figure 1 and Figure 2. However, if a syphon is established the pumping power does not decrease because the static head is eliminated, but actually increases! An examination of Table 2 shows that pumping power increases with flow, hence higher flow rates require greater electrical power for a given pump.

Pumps for drainback systems are often 250W or larger. Since annual solar savings (typically 50% of the cost of conventionally heating the domestic water) range from about \$60 to \$300, the operating cost for a large pump (see Table 3) can be a substantial portion of the monetary savings. The operating cost for a drainback system with a small load, using natural gas backup and operating in a region with high electric costs, can even equal the solar savings.

In spite of high operating costs, drainback systems have many attractive features, including good freeze protection, good overheating protection, high efficiency and potentially lower cost. Five solutions to reduce high operating costs have been identified. The first is to reduce the static head by elevating the drainback reservoir, such as putting it in the attic. However, this may be difficult to do and may increase the heat loss and render the freeze-protection ineffective if it is in the attic.

The remaining four solutions are presented in Table 4. The first three options require a greater initial cost than Option 4. Option 1 is a particularly poor choice if natural gas provides the auxiliary heating and the cost of electricity is expensive, since the water to the collectors is being heated electrically. For a 160W pump with a 10% overall efficiency, 144W would be lost to the water. If the system has a 5.6 m^2 collector array being irradiated at 317 W/m^2 and an instantaneous collector efficiency of 50%, then the electric energy lost to heating the water is equal to about 16% of the collected energy. Hence, this approach can adversely affect system performance.

Options 2 and 3 require one pump or pump speed to assist meeting or meet the static head and then another pump or pump speed that provides for circulation of the fluid.

Table 4
Drainback Options to Reduce Operating Costs

Advantages	Disadvantages
1. Submersible pump:	
• Reclaims all lost pump motor heat • No special controls or timers	• Not suitable for many systems (e.g., systems with sealed drainback tanks) • Reduces collector efficiency by pre-heating collector loop water electrically • Maintenance more difficult • Initial cost is greater than that of conventional pump • Requires higher temperature materials • Requires waterproof case and wiring
2. Two pumps with timer for one pump:	
• Conventional pumps • Conventional plumbing	• Additional initial and installation cost • Increased maintenance • Additional controller capability or timer required
3. Two-speed pump with timer:	
• Conventional plumbing	• Initial cost greater than that of a single-speed pump • Requires timer
4. Pump speed controller:	
• Small additional cost • Conventional pump • Conventional plumbing	• Requires compatible motors • Not currently available commercially

The fourth option was built and tested at SERI. It consists of a triac and time delay circuit which can be incorporated into a conventional control system with little additional cost. The pump speed controller provides full power to the pump initially to overcome the static head and then after a specified time delay (corresponding to the time needed to establish a syphon plus an error margin), reduces power to the pump by phase control used to regulate the on- and off-time of the A.C. sine wave. Initial experiments at SERI have shown this approach to work reliably and to reduce operating costs by at least 40% for drainback systems.

5. CONCLUSION

Low pump efficiencies of less than 16% and correspondingly high operating costs in solar domestic hot water systems have been experimentally determined. This can lead to operating costs in SDHW systems that are a significant portion of the savings, particularly in drainback systems. Five possible methods of reducing the operating costs of drainback systems have been considered and the most promising, an inexpensive pump speed controller, was built and tested at SERI. Initial results of the pump speed controller testing have been encouraging.

6. ACKNOWLEDGEMENTS

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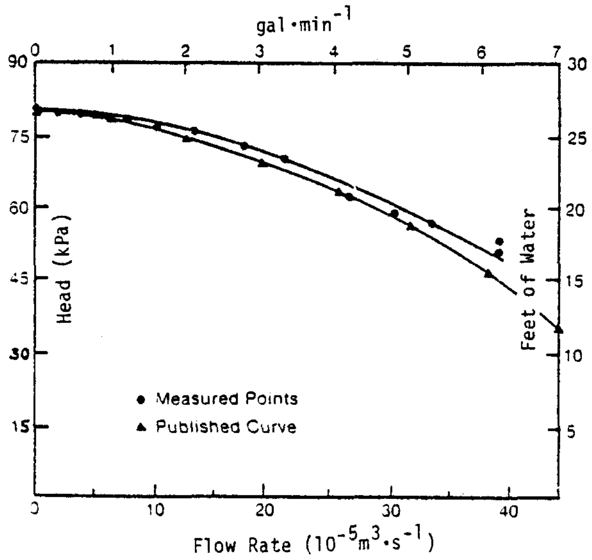

Fig. 1. Taco 009 Pump Head Versus Flow Curve

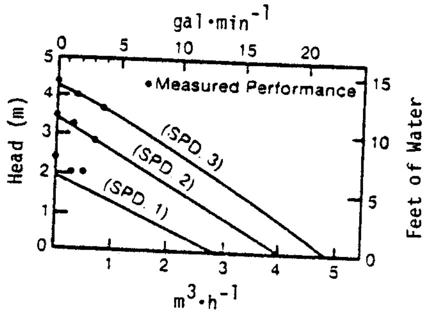

Fig. 2. Grundfos UPS 20-42 Pump Head Versus Flow Curve