This paper was subsequently published in the
Proceedings of the 1999 ACEEE Summer Study of Energy Efficiency In Industry

We've Been Testing Water Pumps For Years – Has Their Efficiency Changed?

Thomas Conlon, GeoPraxis, Inc.[1], Glen Weisbrod, Economic Development Research Group,
Shahana Samiullah, Southern California Edison

April 1999

ABSTRACT

This paper presents selected results from the analysis of over 28,000 pump tests performed by Southern California Edison between 1990 and 1997 through its Hydraulic Services Program. Begun in 1911, the "Pump Test" program is believed to be one of the nation's oldest continuously operating industrial and agricultural energy efficiency programs. It currently provides energy efficiency information and 4,000 - 5,000 free pump tests per year to over 650 agricultural and municipal water pump end users, reaching 52% of all energy consumed in the sector. This analysis was conducted as part of a comprehensive "market effects study" which developed and tested a set of hypotheses on how the program may have affected a wide-range of market barriers to the adoption of cost-effective energy efficient water pumping equipment and services. The study was designed with assistance of the California Demand-side Management Advisory Committee (CADMAC), and was one of four such studies extensively reviewed by consultants to the California Board for Energy Efficiency in the context of market transformation.

Introduction

This paper reports on our analysis of the immensely rich database of pump test results spanning seven years of data collection by Southern California Edison pump test technicians. This analysis was only one facet of a much broader study that investigated the market effects associated with Southern California Edison's Hydraulic Services Program.[2] Readers interested in the methodological issues raised by the project and our other findings are encouraged to seek out other published sources on the study (Peters, et al. 1998a; Peters, et al. 1998b; Peters, et al. 1998c; Conlon, Weisbrod, and Samiullah 1999). According to our review of the literature and discussions with leading pumping experts, we believe that no larger data set of pump testing results has previously been published.

Background

Southern California Edison's Hydraulic Services (Pump Test) Program is one of the largest and longest running pump-related energy efficiency programs in the country. The program provides municipalities, agricultural, and other water pumping customers with a pump

[1] This paper reports on work completed while Mr. Conlon was a Senior Consultant at RLW Analytics.
[2] We designed the project to closely follow the paradigm developed in the Market Transformation Scoping Study (Eto, Prahl, & Schlegel, 1996).

efficiency test that determines overall system efficiency, electrical motor performance, pump hydraulics and water well characteristics. The pump test compares the relationship between energy consumed (in terms of kWh) and water flow (in terms of gallons per minute) at a given pumping head (in terms of feet). The result is a computer-generated report containing the estimate of overall efficiency of the pumping plant, which includes the motor, pump assembly and applicable distribution system. If performance is found to fall below industry standards, and a replacement or upgrading of equipment is warranted, then the customer is issued a cost analysis letter. This letter includes estimates of the capital and operating costs associated with repairs or a new system. Issues that may affect tested efficiency are addressed, including motor efficiency, variable speed drives, piping system friction loss, excess pumping pressure, reservoir storage and energy management. If after assessing overall plant efficiency, no change in equipment is warranted, then the customer gets a "congratulatory" letter.

Targeted end users. The tests are focused on two broad categories of customers:

1. Agricultural (irrigation) customers – primarily growers, poultry, stock or dairy operators, plus a few golf courses; irrigation districts also serve some groups of agricultural customers.

2. Water Supply customers – including municipal agencies and private water companies.

In 1996, the program tested pumps belonging to some 294 Agricultural customers and 296 water supply customers. Most of the agricultural customers participating in the program are concentrated in northern parts of the utility service area, while water supply customers are concentrated in the southern "metro" area.

Targeted pump types. The program focuses on the most commonly used types of water pumps used for agricultural crop irrigation and municipal water service. These are:

- The ***deep well turbine*** -- a vertical centrifugal pump mounted at the bottom of a well, provides higher-pressure flow from deep wells. A line shaft separates the (top) motor from the (bottom) bowl assembly, which contains one or more impellers and bowls.
- The ***horizontal centrifugal pump*** -- a single-stage impeller unit mounted on a horizontal axis. It is used in applications requiring large water flow at low pressure, such as irrigation.
- The ***submersible pump*** -- less common; used instead of deep well turbine where above ground space is at a premium or straight line access to the water source is not possible. Like the deep well turbine, it provides higher-pressure flow.

In general, the water supply customers operate a wide range of pumps including very large, high flow capacity pumps. Agricultural customers typically operate smaller volume pumps. Exceptions to these basic types occur. For both types of customers, many of the pumps can be powered by an electric motor or by a diesel or natural gas-driven engine. The choice of fuels is determined largely by local site availability as well as air quality regulations. Southern California Edison's program provides services mostly for electric motor driven pumps.

Scope

The portion of our study reported here is based on a program tracking system assessment that developed participation counts and program penetration estimates, and documented motor and overall pump efficiency trends over the past seven years. The study also included an extensive review of secondary sources including former Edison market research, and past market and field pump testing studies done by others (Abernathy ND; EPRI 1997; Fipps and Neal, 1995; Fischbach and Dorn, 1981; Neal and Fipps, ND; New, 1986; New and Schneider, 1988; Schneider and New, 1986; Schneider and New, 1990; Solomon and Zoldoske, 1994). Past Edison impact evaluation surveys (1992 and 1996) of agricultural and water supply customers provided additional data on non-participant and third-party pump testing trends. Edison's approach was designed to leverage these existing secondary sources rather than perform extensive new customer surveys.

Methodology

The overall "wire-to-water" efficiency of a pumping plant is the relationship between the energy consumed (in kWh) and the amount of water or other fluid being delivered (in gallons per minute) at a given pumping head (in feet). The greater the overall efficiency of the pumping plant, the lower the overall pumping costs will be. Edison's pump test technicians measure pump performance in situ, allowing end users to track pumping plant efficiency and determine when maintenance or overhaul will be cost-effective (Southern California Edison, ND).

Pumping plant efficiency is determined by analyzing the water level in a well during pumping, discharge flow rates, and power inputs to the pump motor. In order to determine the pumping water level, it is essential to sound the well. Some pumps have sounding access holes in the pump head. Newer wells may include an "airline" which can provide rapid determination of water levels. If neither of these is available, a "sounding tube" consisting of a 1 1/4" pipe with a smooth edge can be welded to the pump casing.

In order to obtain flow rate (gallons per minute), a pitot tube must be inserted in the discharge pipe. All pump discharge pipes should be accessible for pitot tube insertion. The *ideal* length of the discharge pipe ahead of the pitot tube access point is eight times the discharge pipe diameter. The flow rate measurement should be taken from a straight section of pipe, free of all fittings (e.g., check valve, water meter, etc.). This prevents turbulence from affecting the accuracy of the flow measurement. Water meters can be used to monitor pump performance on a continuing basis.[3]

Put simply, the overall plant efficiency relationship is:

[3] With centrifugal pumps the test hole may be on either the suction or the discharge side of the pump, depending upon pressures. When more than one pump is connected to a common manifold, the manifold may provide a better test location. PVC pipe may require a greater upstream length ahead of the test hole.

$$\text{Overall plant efficiency (\%)} = \frac{\text{Water Horsepower}}{\text{HP input}} \times 100$$

Where:

$$\text{Water Horsepower (output HP of pump)} = \frac{\text{GPM} \times \text{Total Head}}{3{,}960}$$

$$\text{HP Input (to motor)} = \text{kW input} \times 1.341$$

Total head = Discharge head + pumping water level, ft.

Discharge head = Discharge pressure, PSI × 2.31 ft. of head

$$\text{Motor load (\%)} = \frac{\text{HP input} \times \text{Motor efficiency in percent}^{4}}{\text{Name plate HP of motor}}$$

3,960 = 33,000 Ft. Pounds/HP ÷ 8.33 lb. of water/gallon

Beyond measuring plant performance, Edison personnel also offer recommendations to capture efficiency and cost saving opportunities elsewhere in the pumping system. These considerations may include minimizing piping friction losses, maintaining adequate pumping pressure, matching pressure to varying flow requirements through variable speed drives, and priority pumping and/or reservoir storage strategies.

Selected Results

The remainder of the paper is devoted to reporting on the results of the tracking system assessment and the analysis of the pump test data itself.

Program Market Share

Edison program records were analyzed to estimate the pump testing program's penetration in the agricultural and water supply segment. Table 1 reports program market penetration at the premises level and at the corporate customer level (including all affiliated premises).

Table 1. Pump Test Program Market Penetration

Ag. & Water Supply	Premises		Corporate Customers	
	(N)	Energy (GWh)	(N)	Energy (GWh)
SCE Pump Tested	19%	52%	13%	66%
Non-Participants	81%	48%	87%	34%
Total	100%	100%	100%	100%

[4] From lookup table if name plate data is unavailable.

This assessment is based on a February 1997 Edison agriculture and water supply population extract crossed with the populations of pump tests performed and rebates paid during the four year period, 1993-1996 (inclusive).[5] A total of 6,861 unique premises were tested during this four-year period. Some premises received more than one test during this time. Only 9% of the premises tested received a rebate for an energy efficiency improvement from Edison during the same period, indicating the degree of overlap between the testing (information) and incentive programs.

The program reached 19% of all premises, but 52% of all energy consumed at the premises level. At the corporate customer level, the program reached only 13% of customers, but these were responsible for two-thirds of the energy consumed in the segment.

Pump Test Database

Over 28,000 records of individual pump tests performed between January 10, 1990 and April 9, 1997 were analyzed for the study. Figure 1 shows the distribution of tests by nameplate motor horsepower. Nearly all of the tested pumps had motors of 20 hp or larger. The average motor horsepower was approximately 77 hp for the agricultural customers, 94 hp for the water customers, 110 hp for golf course and 96 hp for miscellaneous other customers in the program. Turbine well type pumps are the most commonly tested, accounting for 52% of all those tested. Turbine boosters take up 23% of the test population, while submersible well types account for 12%. Centrifugal boosters represent 11% of the total while submersible boosters account for the remaining 2%.

Motor and pumping plant efficiencies are shown according to the type of pump tested in Table 2 and Table 3. Submersible well type pumps stand out as being significantly less efficient than the other types tested. This is believed to be the result of several factors. Submersibles are popular for smaller HP applications, leading to a smaller average HP for pumps of this type. In these applications, buyers tend to be especially interested in low capital costs, encouraging manufacturers to produce more inexpensively made models. Finally there seems to be some anecdotal indication from pump testers that the motors driving these pumps are more likely to be overloaded, leading to poorer overall energy performance (Paul Williams, SCE, personal communication April 29, 1999).

[5] The population includes both pump tariff and non-pump tariff customers. Rebate years are 1993, 1994, and 1996. Edison did not provide rebates in 1995.

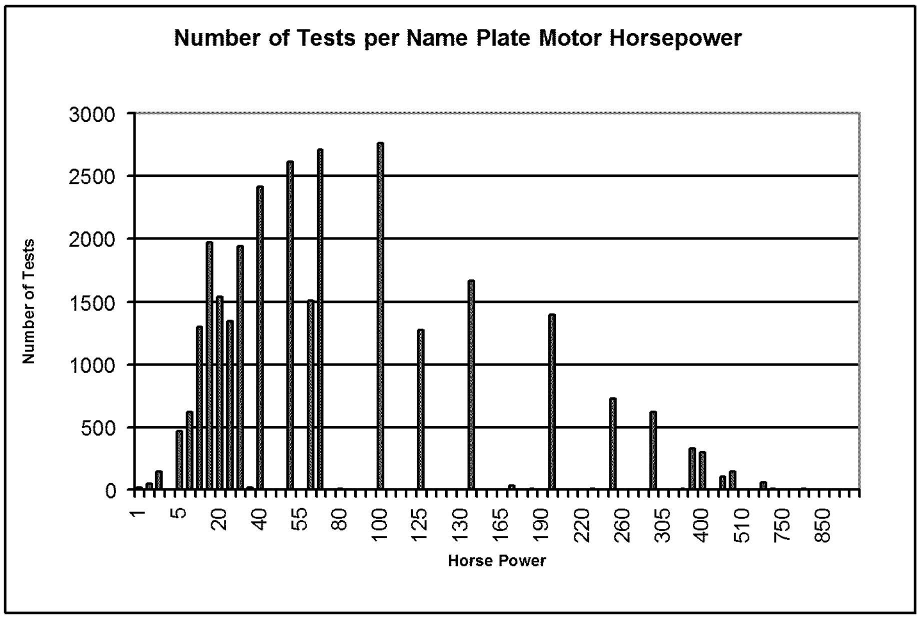

Figure 1. Distribution of Motor Sizes for Tested Pumps

Table 2. Average Motor Efficiency, by Pump Type

Average Motor Efficiency, by Pump Type and Test Year									
PUMP TYPE	1990	1991	1992	1993	1994	1995	1996	1997	Average
Centrifugal Booster	88.1	88.4	88.6	89.1	89.0	88.9	88.8	89.2	88.8
Submersible Booster	82.9	85.7	85.9	86.5	86.0	85.5	86.2	84.7	85.9
Submersible Well	80.4	81.4	81.5	81.9	82.0	82.4	82.4	83.4	81.9
Turbine Booster	90.1	90.3	90.6	90.7	90.8	90.8	91.0	91.6	90.8
Turbine Well	89.9	89.9	90.0	90.3	90.3	90.6	90.5	91.1	90.3

Table 3. Average Overall Plant Efficiency, by Pump Type

Average Overall Plant Efficiency, by Pump Type and Test Year									
PUMP TYPE	1990	1991	1992	1993	1994	1995	1996	1997	Average
Centrifugal Booster	54.5	54.4	55.1	56.5	56.8	55.0	55.1	52.1	55.4
Submersible Booster	54.7	54.9	58.6	58.4	57.5	58.8	61.0	53.6	58.4
Submersible Well	42.1	43.9	44.4	43.7	43.7	45.4	43.8	48.2	44.2
Turbine Booster	69.0	63.0	62.7	61.2	62.4	62.3	63.5	65.1	62.8
Turbine Well	55.6	55.5	55.2	56.4	56.3	57.7	57.4	57.7	56.4

Simple linear regression equations were developed to further describe the motor efficiency and overall plant efficiency (OPE) trends for each of the customer types.[6] The regression results are reported in Table 4 and Table 5. Given the variance of the small samples of

[6] This analysis included some additional data cleaning that resulted in some minor changes to the 1990 average overall plant efficiencies reported above. Removal of all observations with efficiency values < 1.0%, or > 100%, or in "1999"; missing values were excluded from this and prior analyses as well.

golf and sewer tests, the OPE trends identified for both groups and the motor efficiency trend for sewage pumps are not considered statistically significant (strikeout text).

Table 4. Motor Efficiency Trends, All Tests

Motor Efficiency Yearly Increase Trend—All Sites Tested						
	Obsv.	1990	%/Yr. Coeff.	Std.Er	Lower 90%	Upper 90%
Ag	11,055	88.0%	0.200	0.021	0.165	0.235
Golf	634	89.5%	0.162	0.082	0.027	0.296
Other	3,591	88.6%	0.151	0.038	0.088	0.214
Sewage	344	~~89.2%~~	~~0.077~~	~~0.110~~	~~-0.105~~	~~0.259~~
Water	11,924	88.8%	0.158	0.020	0.125	0.191
All	27,548	88.5%	0.183	0.013	0.161	0.205

Table 5. Overall Plant Efficiency Trends, All Sites Tests

Overall Plant Efficiency Yearly Increase Trend—All Sites Tested						
	Obsv.	1990	%/Yr. Coeff.	Std.Er	Lower 90%	Upper 90%
Ag	10,422	53.6%	0.436	0.071	0.319	0.554
Golf	602	~~57.7%~~	~~0.355~~	~~0.279~~	~~-0.104~~	~~0.814~~
Other	3,399	53.8%	0.630	0.124	0.427	0.834
Sewage	317	~~59.9%~~	~~-0.047~~	~~0.372~~	~~-0.660~~	~~0.566~~
Water	11,315	55.8%	0.415	0.066	0.306	0.524
All	26,055	54.6%	0.476	0.044	0.403	0.549

Beginning with an average motor efficiency of 88.5% in 1990, motor efficiencies in the pump test population were found to be increasing by a rate of 0.18% per year. Overall plant efficiencies were found to be rising from a baseline of 54.6% in 1990 by the rate of 0.48% per year. These annual rates of increase may appear to be small in comparison to the potential savings opportunities at any given facility found to be operating below industry standards.[7] To understand these results, it must be remembered that the population of pumps tested changes each year. Edison intentionally targets its testing to pumps that have not been tested recently (or may never have been tested). In addition, during the time period we analyzed Edison has taken steps to be even more selective, extending the period of time between retesting of pumps so as to reach more pumps that have been tested infrequently or never before.

In order to understand how these trends have been influenced by Edison's rebate programs, the pump test data was split into two sets:

- Test program participants who also received a rebate during 1993, 1994, or 1996[8] (11.5%)
- Test program participants who did not receive a rebate in those years (88.5%).

Figure 2 and Figure 3 compare the rates at which efficiency is increasing each year in the rebate and pump test only groups. Agricultural sites are responsible for the greatest increases in

[7] A case study of a typical turbine well pump suggests that overall plant efficiency can be increased from 40% to 68%, by reducing losses in the bowl assembly, column and shaft, and motor bearings. Overall plant efficiencies as high as 72% can be achieved with pumps in the 300 HP range (SCE, ND).
[8] No rebates were offered in 1995.

motor efficiency, while "Other" sites show the greatest increases in overall plant efficiency. Regardless of customer type, both motor and overall plant efficiencies are increasing at a greater rate at rebate sites. Rebate sites show a much stronger rate of increase in overall plant performance (1.26% per year), as compared with their increases in motor efficiency alone (0.26% per year). By comparison, the rates of increase are more moderate at pump test only sites (0.38% per year in OPE and 0.17% per year in motor efficiency).

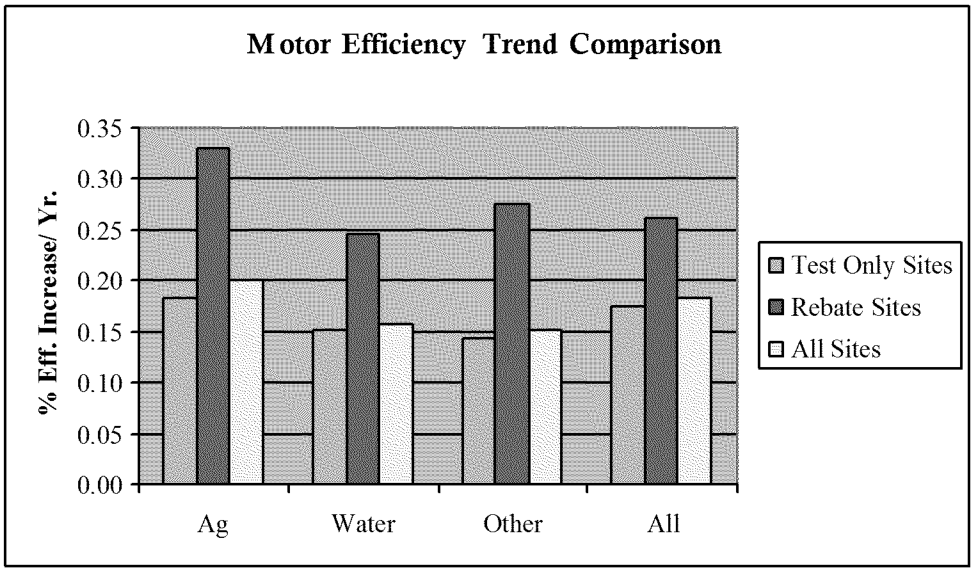

Figure 2. Comparison of Motor Efficiency Yearly Increases

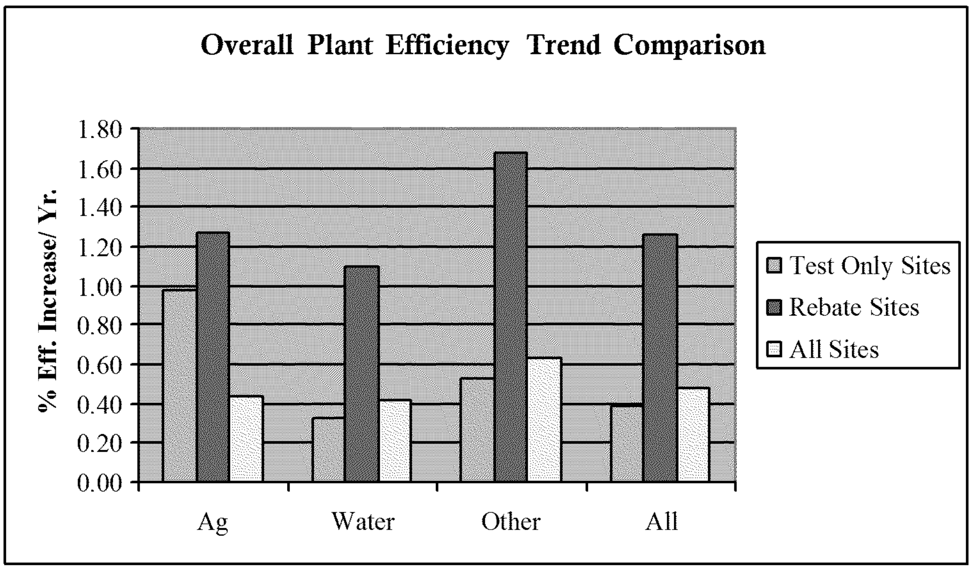

Figure 3. Comparison of Overall Plant Efficiency Yearly Increases

The relationships between the motor, other (non-motor), and overall plant efficiency increase trends are summarized in Figure 4. This comparison shows that for all sites, motor improvements alone are responsible for less than half of the increase in overall system efficiencies. This contradicts popular assumptions held by dealers and others that high efficiency motors are the primary drivers of increasing efficiency in water pumping. For both rebate and pump-test only sites, the majority of the improvement in overall pumping plant efficiency occurs in the residual category of all other efficiency improvements. In particular, rebate sites owe only a small share of their overall plant improvements to higher efficiency motors. Sites receiving pump tests alone can credit a greater share of their overall plant improvements to higher efficiency motors, but still less than half.

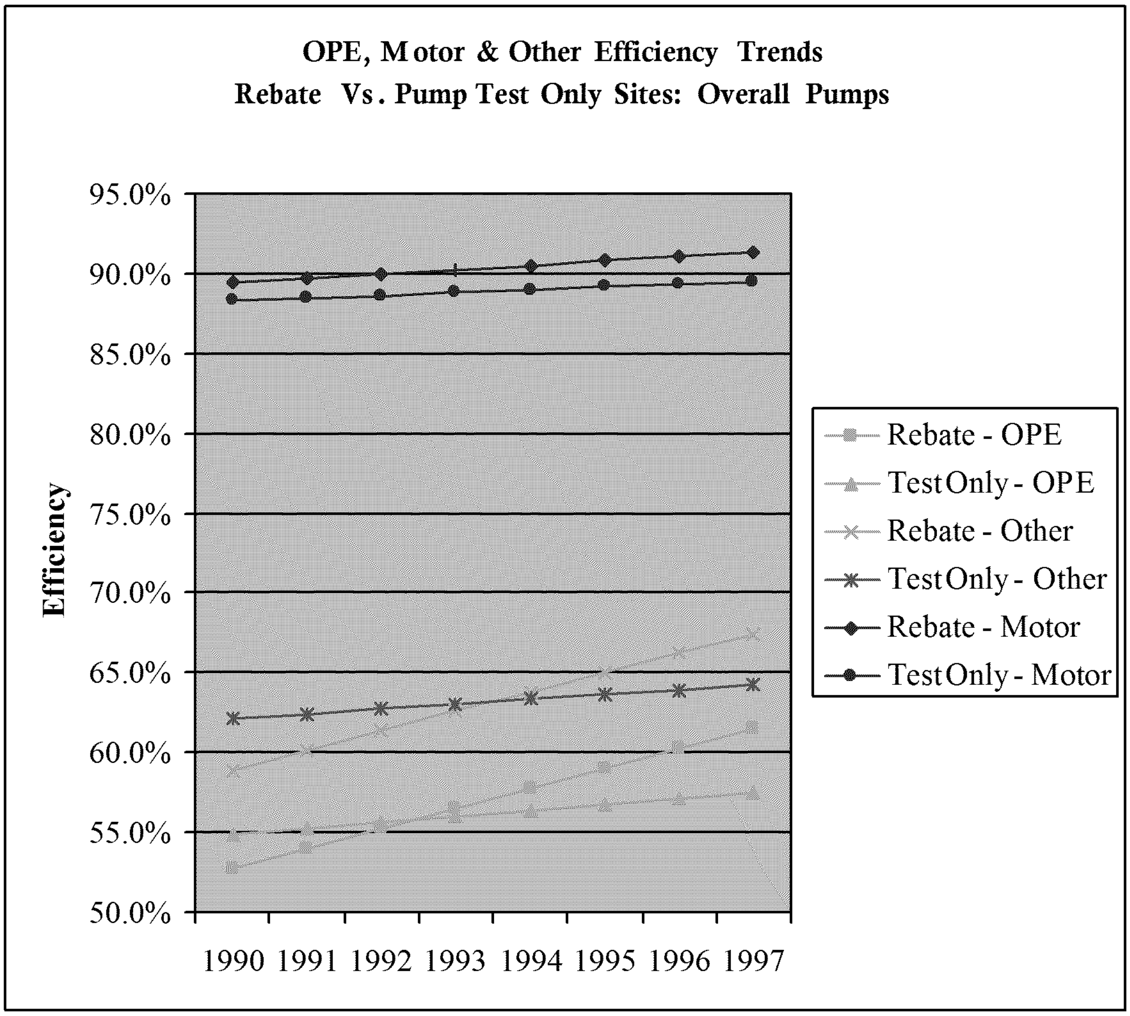

Figure 4. Comparison of Efficiency Trends – All Pumps Tested

Conclusions

(1) Over a four-year period, the program reached 19% of all premises in the segment, but fully 52% of all energy consumed at the premises level. Edison and others interested in pursuing future broad-based public policy goals to improve energy efficiency in the pumping end use should explore opportunities for combining efforts to exploit this type of program's inherent strengths as a vehicle for transferring best practices and new technologies to customers and dealers. Future program goals should include 1) expanding the program to coordinate with new and existing pump testing programs to enable consistent cross-regional implementation and record keeping and to maximize administrative efficiencies, and 2) setting new cumulative participation targets.

(2) For program participants over the past seven years, overall plant efficiency has increased at a greater rate (0.48% per year) than motor efficiency (0.18% per year). Motor improvements alone were found to be responsible for less than half of the increase in overall system efficiencies. This contradicts popular assumptions expressed by some dealers and others that high efficiency motors are the primary drivers of increasing efficiency in water pumping. This trend was observed, regardless of whether the site received a rebate or only pump tests. According to Edison survey data (1996), these other improvements appear to be related primarily to replacements of pump and pump tube components, as well as to some improvements in the electrical and control components. This finding is consistent with the analysis contained in the recently published Motor Challenge Program Market Opportunities Assessment (Xenergy, 1998). This report indicates that the majority (62%) of the savings potential in industrial motor systems nationally is bound to efficiency improvements to the major fluid systems (including pumps, fans and air compressors).

(3) Among program participants, agricultural sites have been responsible for the greatest increases observed in motor efficiency (0.20% per year). Considering that agricultural sites started out in 1990 with the lowest level of motor efficiency (mean = 88.0%) compared to other submarkets, this finding indicates that as of 1997, most of that difference had disappeared. This was true, even without correcting for the lower average HP of the agricultural pumps tested.

(4) In contrast, the "Other" category of participating sites has shown the greatest increase in overall plant efficiency (0.63% per year). Again this segment started out in 1990 with a relatively low level of overall plant efficiency (mean = 53.8%).

(5) Regardless of customer type, both motor and overall plant efficiencies were found to increase at a greater rate at those sites which received utility rebates. Rebate sites show a much stronger rate of increase in overall plant performance (1.26% per year), as compared with their increases in motor efficiency alone (0.26% per year). By comparison, the rates of increase are more moderate at pump test only sites (0.38% per year in OPE and 0.17% per year in motor efficiency). As demonstrated by the crossing trend lines in Figure 4, rebates have generally gone to those sites that were

initially performing below the norm, ultimately resulting in above norm performance. Pump test only sites have experienced more moderate, but consistent, efficiency improvements.

We believe that the publication of these findings is important because it provides a point of reference for pumping facility operators, research engineers, and program designers elsewhere who are interested in field-measured pump performance data. Interested readers are encouraged to contact us for further information.

Acknowledgements

The authors wish to thank all the very helpful people who filled our data requests, answered our tireless questions, and made this research possible. In particular we wish to acknowledge the technical assistance of Paul Williams at SCE. We also appreciate the candor and perceptive comments of the many reviewers of our original report, including Ralph Prahl, Joe Eto, and Ken Keating, and the members of the CADMAC Summary Study Team organized by Jane Peters.

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