IRRIGATION PUMPSET EFFICIENCY IN DEVELOPING COUNTRIES: FIELD MEASUREMENTS IN PAKISTAN

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ABSTRACT. *The mechanical efficiency of 132 privately owned irrigation pumpsets in Pakistan was measured. The average overall efficiency was 54 and 48% of the Nebraska Pumping Plant Performance Criteria (NPPPC) for electric and diesel powered centrifugal pumpsets, respectively. Forty-four pumpsets were improved using local technology. This article presents details and results of this project.* **Keywords.** *Irrigation, Pumps.*

Recent growth in irrigation water supply and resulting food production in Pakistan has been primarily due to groundwater development (Government of Pakistan, 1986). There are an estimated 300,000 irrigation pumping plants in Pakistan at present. The number of new installations is increasing at rate of about 10,000/y. Increased groundwater development and associated energy use in agriculture is likely to continue.

Pumping plant configurations typical of those found in Pakistan are illustrated in figure 1. Privately owned pumping plants in the Indus river valley account for over 90% of the national total. The current division by prime mover type is (Government of Pakistan, 1984):

Electric motor	50%
Slow speed stationary diesel engine	35%
High speed stationary diesel engines and tractors	15%

The fastest growth is being experienced by electric followed by high speed diesel and tractor powered pumps. Slow speed diesel engines are no longer being manufactured and the number of operational units is declining. Annual operation is about 3,000 h for electric and 1,000 h for diesel powered pumpsets. The operational cost of electric pumpsets is considerably lower than for diesel pumpsets accounting for their greater use.

About 95% of the pumps used for irrigation pumping are horizontal shaft suction lift centrifugal pumps. Submerged turbine pumps make up the remaining 5%.

In 1988 the electrical energy consumed for irrigation amounted to about 4,415 gWh (1.05 million t of Oil Equivalent, TOE). This accounts for about 18% of national electric generation and 25% of peak demand (Government of Pakistan, 1988). The demand for electrical energy in Pakistan far exceeds supply. Rural areas are commonly without electrical power 12 or more hours per day during critical periods.

The diesel fuel consumed in irrigation pumping plants in 1988 amounted to 420,000 TOE (Government of Pakistan, 1988). This is about 5% of the national petroleum use.

Irrigation is thus a major consumer of the energy resources of Pakistan. An energy conservation program dealing with irrigation pumping was undertaken with the following objectives:

- Document the energy efficiency of electric and diesel irrigation pumping plants in the various regions of the country.
- Determine sources of inefficiency
- Demonstrate measures to improve energy efficiency.

This article describes the activities undertaken to achieve these objectives. This study confined itself to investigations of the mechanical efficiency of pumping machinery as other programs addressed water use efficiency. Increasing

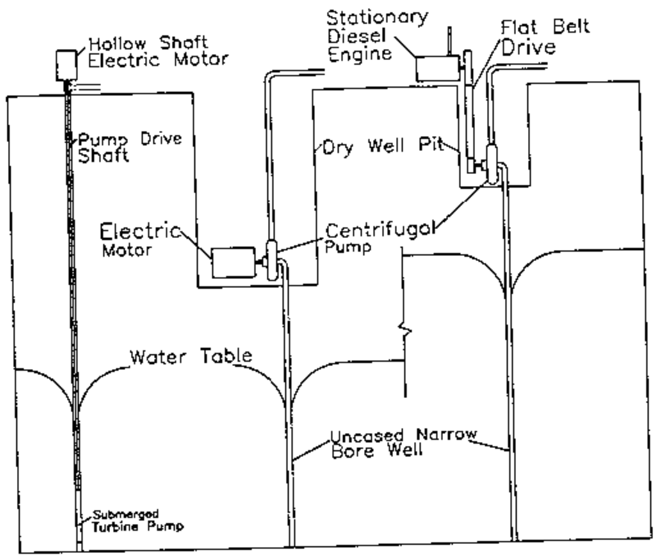

Figure 1–Typical pumpset components.

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the efficiency of water use is another critical aspect of reducing the energy requirements for irrigation.

MATERIALS AND METHODS

Energy audits were performed on 132 privately owned irrigation pumpsets. Table 1 presents details of prime mover and pump types of the audited pumpsets, figure 2 lists the instrumentation, parameters measured, and calculation scheme.

Overall pumping efficiencies were determined from direct measurements. Overall efficiency is defined as the power input divided by the water power output of the pump. Power input is either electrical energy for motors or primary fuel consumption for engines. Prime mover efficiencies were estimated from measurements of indirect parameters and comparison with typical performance criteria. Belt drive transmission efficiencies are correlated with measured belt slip. Pump efficiencies were estimated from measured overall efficiencies and estimates of transmission and prime mover efficiencies.

Efficiencies were compared to the Nebraska Pumping Plant Performance Criteria (NPPPC), (University of Nebraska, 1982). The NPPPC resulted from extensive field pump testing in the United States. They are indices of expected pumping plant efficiencies. Comparisons with the NPPPC may be over 100% for equipment which is very efficient.

Retrofits were performed on 44 of the audited pumping plants to assesses the effectiveness of locally available technology in increasing pumping efficiency. Three main categories of retrofits were performed:

- **Pump repair.** This included normal maintenance and replacement of worn parts and trimming oversized impellers. More extensive repairs were done when needed. These included replacement of cottage industry impellers with brand name impellers and installation of seal cages on pumps without. Several brand name pumps replaced cottage industry pumps.
- **Diesel engine repair.** This included minor adjustments and maintenance such as adjusting valve clearance and cleaning injectors. Several engines had injectors, sleeves, rings, and pistons replaced.
- **Other general repairs.** These included adjustment and repair of belt transmissions and installing properly sized piping.

Table 1. Audit results of 74 electric centrifugal pumpsets

	Average	Maximum	Minimum
Power consumption (kW)	9	29	1
Power factor (%)	81	94	58
Discharge (L / s)	27	53	1
Dynamic suction head (m)	7	9	4
Total dynamic head (m)	14	62	6
Most efficiency (%)	75	89	40
Pump efficiency (%)	48	76	6
Overall efficiency (%)	37	67	5
Motor (% of NPPPC)	85	101	45
Pump efficiency (% of NPPPC)	64	101	8
Overall efficiency (% of NPPPC)	56	101	8

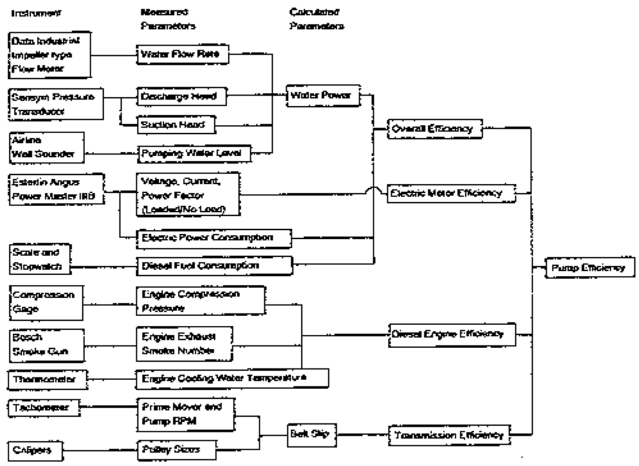

Figure 2–Instrumentation, measurements, and calculated parameters.

RESULTS AND DISCUSSION

Tables 2, 3, and 4 summarize the results of the energy audits. The average efficiency of all centrifugal pumps was 64% of the NPPPC. Centrifugal pumps were the component with the lowest efficiency rating. The two primary reasons for low centrifugal pump efficiency were

Table 2. Frequency of retrofit measures

Retrofit Measure	Frequency
Electric Motors(10 repaired)	
Motor rewinding	1
Replace bearings	8
Other minor repairs	7
Diesel Engines (9 repaired)	
Temperature control added	6
Rings and sleeve replaced	3
Bearings replaced	1
Fuel pump repaired	2
Governor repaired	3
Valve seats replaced	2
Other minor repairs	7
Pumps (44 repaired)	
Impellers trimmed or replaced	30
Shaft resurfaced	37
Bearings replaced	27
Wear ring replaced	22
Seal cage installed of repaired	24
Bushings replaced	22
Gaskets replaced	30
Pump replaced	2
Other minor repairs	41
Transmissions (19 repaired)	
Belt replaced	12
Pulley replaced / resized	7
Coupling repaired	2
Other minor repairs	6
Piping (28 repaired)	
Pipe replaced / resided	9
Foot valve repaired / replaced	6
Other minor repairs	11

Table 3. Audit results of 12 electric turbine pumpsets (eight submersible, four line shaft turbine)

	Average	Maximum	Minimum
Power consumption (kW)	12	28	4.0
Discharge (L / s)	11	19	4.3
Field head (m)	51	82	28
Power factor (%)	85	92	69
Motor efficiency (%)	76	88	67
Pump efficiency (%)	57	80	42
Overall efficiency (%)	43	62	33
Motor efficiency (% of NPPPC)	86	100	76
Pump efficiency (% of NPPPC)	76	107	56
Overall efficiency (% of NPPPC)	65	94	50

improper sizing of the pump for its application, and low quality pumps.

Centrifugal Pump Sizing

Pumps are commonly oversized. Larger pumps are assumed to deliver more water. The limiting factor in most cases, however, is the yield of the well. An oversized pump will draw the well down to the suction capacity of the pump. Cavitation will occur if the pipe joints and gland packing are air tight. This will result in reduced pumping efficiency and damage to the impeller. An air leak in either a suction pipe joint or the gland packing will often occur before the onset of cavitation. Air intake limits pump output and significantly reduces pumping efficiency. Many pumps were operating at or near the limit of their suction capabilities resulting in reduced efficiency and shorter life.

The most common pump used for irrigation purposes is a 15.2 cm (6 in.) inlet and 12.7 cm (5 in.) outlet (6×5). These 6×5 pumps accounted for over 80% of irrigation installations in 1984 (Government of Pakistan, 1984). They represented a similar percentage of the pumpsets audited in this study. These pumps are usually installed on uncased wells. The most common diameter suction pipe is 15.2 cm (6 in.). The average yield of such wells in the Punjab was about 100 m^3/h (1 ft^3/s). The average total dynamic head was about 12 m (39 ft) of water.

Figure 3 illustrates characteristic curves for two common centrifugal irrigation pumps. The theoretical discharge of the smaller pump (4×3) is within 10% of the larger (6×5) at a total dynamic head of 12 m. The efficiency of the smaller pump will, however be considerably higher. The smaller pump will have lower

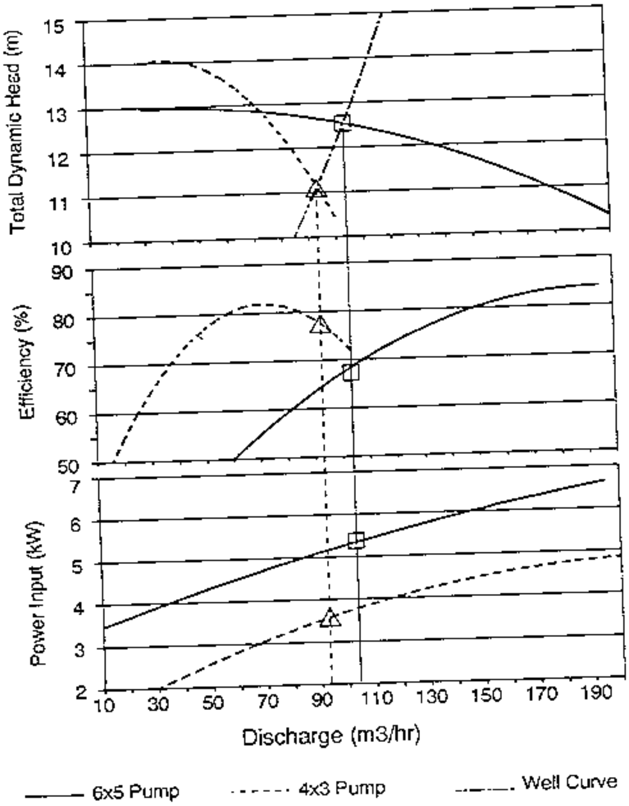

Figure 3–Typical centrifugal pump performance curves.

initial, repair, and energy costs. Even greater energy and repair savings will result when comparing a 6×5 low quality pump with a 4×3 high quality pump.

The total dynamic head of a well commonly increases with time due to blockage of the well screen and/or surrounding aquifer. Increased frictional losses also occur due to deposits in well piping. The draw-down for a given discharge therefor increases. A falling water table will also increase pumping head.

The preferred operating point for a new pump is slightly to the right of the point of maximum efficiency (fig. 3). The pump discharge is least affected by head changes in this region of the head/discharge curve. Thus as total dynamic head increases, pumping volume decreases only slightly and efficiency increases. The 6×5 pump will suffer far greater losses in pumping volume and efficiency for an equal increase in pumping head.

Table 4. Audit results of 46 diesel centrifugal pumpsets (19 high speed diesel, 15 slow speed diesel, 12 tractor)

	Average	Maximum	Minimum
Fuel consumption (L / h)	2.4	5.1	0.9
Discharge (L / s)	25	41	6.0
Dynamic suction head (m)	6.8	8.7	4.0
Total dynamic head (m)	12	18	7.3
Engine efficiency (%)	25	30	10
Pump efficiency (%)	48	80	25
Overall efficiency (%)	11	17	6.0
Engine efficiency (% of NPPPC)	80	97	32
Pump effiency (% of NPPPC)	64	107	33
Overall efficiency (% of NPPPC)	48	74	27

Centrifugal Pump Quality

Small, "cottage industry" pump shops produce many of the centrifugal pumps used in Pakistan. The quality of these pumps is extremely variable. Some of the cottage industry pumps perform nearly as well as the "brand name" pumps. There are many, however, whose performance is below acceptable levels. The impeller and casing surfaces are sometimes rough and the vane passages are of unequal size. This results in high friction losses and dynamic unbalance leading to vibration. Sealing of the pump shaft is often inadequate increasing the possibility of air entry under high suction lift conditions.

Farmers have little or no pump performance information available to them. The performance characteristics of cottage industry pumps are often not known by the manufacturer or salesman. The market is also extremely price sensitive. These conditions result in the high frequency of pumps not properly matched to their application.

The quality of pump repair work is also variable. Most pump shops have very little understanding of pumping efficiency. Most repairs bring the pump to a functional level with little regard for efficiency. The main desire of the farmer is that the cost of the pump and its repair is low. Many farmers repaired their pumps every year. During any given month 17 to 28% of government owned irrigation wells were not in working condition. These are indications that the quality of pumping equipment is low and/or that installation, maintenance and repair services are substandard.

Electric Motors

Most electric irrigation pumpsets use three-phase power. Unbalanced phase-to-phase supply voltage on three phase lines were common. Excessively low and high supply voltage were also common. Low supply voltage and unbalanced phase-to-phase voltage contribute to the high occurrence of motor burnout. Motors were typically oversized as protection against these effects. Over-sizing motors results in reduced power factors and reduced efficiency. Repeated burnout and rewinding also reduce motor efficiency. The primary solution to these problems lies in increasing the quality of electric power delivered to farms.

Diesel Engines

Overcooling was a serious problem in many engines. A common notion among farmers is that engines should run 'cool to the touch'. The most common method of cooling stationary high and slow speed diesel engines was a tap from the well discharge pipe. Ground water temperature is far below the recommended level for engine cooling water. Engines which run cold are less efficient and experience accelerated engine wear. Conversations with farmers confirmed this effect. Many complained that their engines would last only two or three years before requiring major overhaul. Farmers were often aware that engines were running poorly or used excessive fuel. They were often unaware of basic operation and maintenance procedures and the causes of premature engine wear.

Irrigation pumps often lose prime due to leaky foot valves. This results in the engine operating without a supply of cooling water until the pump is re-primed. This causes overheating of the engine followed by sudden overcooling. This situation also contributes to premature engine wear and failure.

Belt Drives and Well Piping

Belt drive transmissions were generally found to be operating satisfactorily. This is probably because belt drives are easily observed and can be repaired and adjusted without special tools. Drilled wells had adequately sized piping. It was commonly understood that increased bore size increased the output of drilled wells. This encouraged the use of 6-in. piping in most drilled wells. Undersized piping was observed in several small pumps installed in open wells.

Turbine Pumps

Privately owned turbine pumps are used primarily in areas of extremely deep water tables. The turbine pumps audited were 16% more efficient than centrifugal pumpsets. One reason for this that most of the turbine pumps are brand name pumps. If the intake of a turbine pump is submerged its suction requirements will be met. If it is not submerged its depth must be increased or the discharge must be restricted. Many turbine pumps were operating with partially closed discharge valves. This indicates the prevalence of oversized turbine pumps. Partially closed discharge valves increase total dynamic head and required pumping energy. The efficiency of a pump running under these conditions may still be acceptable.

Turbine pumps are much more costly to install than centrifugal pumps. This is the primary reason for their small market share among farmers. The high price of turbine pumps is partly due to the relatively small sales volume. The distribution and support system and cottage turbine pump industry is therefore undeveloped.

Improving Pump Plant Efficiency

The largest gains in pumping efficiency will result from replacing improperly sized pumps with those more closely matched to the application. These measures were not widely implemented in this project because of funding constraints. Retrofit activities in this study targeted low cost measures. These included adjustment of equipment, minor repairs of pumpset components and education of operators. Impeller diameters were reduced on some pumps to match them more closely to well characteristics. This helped to increase pumping efficiency. The range of adjustments in discharge by trimming impellers is limited, however.

The retrofit measures undertaken increased the efficiency of pumpsets by 28 and 29% for electric and diesel centrifugal pumpsets, respectively. Overall efficiencies of about 60% of the NPPPC could be obtained by implementing low cost repairs on oversized cottage industry pumps. Higher efficiencies required equipment replacement. No turbine pumps were retrofit due to their small numbers and the difficulty of removing turbine pumps from their wells.

Table 5 presents the frequency of various retrofit measures performed. The average simple payback period for these low cost retrofits is 8 months for electric and 11 months for diesel centrifugal pumpsets. The basis of the payback period for electric pumpsets is the actual cost of producing electricity rather than the subsidized rate. The cost of electricity used for irrigation is less than half the cost of generation. This reduces the farmer's incentive to install energy efficient equipment.

Table 5. Energy audits by pump and prime mover type

	Pump Type	
Prime Mover Type	Centrifugal	Turbine
Electric motor	74	12
Slow speed diesel engine	15	--
High speed diesel engine	19	--
Tractor	12	--

The following activities were identified for a large-scale irrigation energy conservation program:

- Develop energy efficiency standards, testing, and certification program for irrigation pumping equipment.
- Educate farmers, dealers, and repair industry concerning proper equipment selection, installation, and maintenance.
- Improve manufacturing skills of cottage industry pump manufacturers.
- Improve skills of pump, engine, and motor repair industry.
- Promote the use of turbine pumps.

Education, regulation, and financial incentives can affect the efficiency of newly installed irrigation pumping plants. The number of new installations is small compared to the number of operational plants. The effects of a program addressing only new pumps would therefor be slow. Existing installations could be improved by intervening in the repair process with educational and incentive programs. The Government will need to provide subsidies for any program to be successful given the current rate structure for electricity.

Summary

Irrigation pumpsets in Pakistan typically operate well below achievable levels as defined by the NPPPC. Cost effective methods of improving the mechanical efficiency of irrigation pumping were demonstrated. A large scale retrofit program could substantially reduce the energy used for irrigation pumping in Pakistan.

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