Irrigation Energy Efficiency and Conservation

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Our (OSU Extension) Interest in This….

- We are looking for ways to conserve water, energy and money
- We have three new projects to quantify the current condition of Oklahoma irrigation systems using this aquifer (DASNR & Water Center Grants)
- We are interested in farmers who would let us test some of their irrigations systems
- If we learn something worthwhile we will distribute the information via the county extension personnel

2013 Farm and Ranch Survey

- In 2013 Oklahoma farmers spent about $22,000,000 to power about 5,351 water pumps
- Cost per acre: $52 for ground water, $17 for surface water
- Types of systems:
  - Electric – 46%
  - Natural Gas – 42%
  - Diesel – 11%
  - LP, Propane, Butenol, Ethanol, etc. - < 1%

(BAE-1530 Taghvaeian)

Irrigation Energy Use

- Energy in the form of fuels or electricity is a major cost to farmers trying to irrigate crops
- The main strategies to lower these costs are
  1. **Use the most cost-effective energy source for the pump drive**
  2. **Improve the efficiency of the engine or motor**
  3. **Improve the efficiency of the pump system**
  4. Improve the efficiency of the water distribution system
  5. Use the most effective management and operations of these systems

Electric Irrigation Motors

+ Typically the cheapest to buy
+ Typically one of the cheapest to run
+ Requires little maintenance (motor) once installed
+ Easy to monitor motor efficiency (watt-meter)

- May not be large enough for deep wells
- Must have utility power available (electric lines)
- Usually needs to be 3-Phase power for larger motors
- Electric Rates (tariff) needs to be geared toward irrigation

Diesel, Natural Gas and Propane Engines

+ Powerful for size (deep wells)
+ Can be in a very remote location
+ Does not need utility lines unless using piped natural gas
- Engines are expensive
- Fuel is expensive and variable cost
- Fuel must transported to the engine (by you?)
- Engines need periodic maintenance
- Fuel or oil spills
- Propane – most expensive fuel option

Example Natural Gas Engine Irrigation Costs

User Input

State: Oklahoma
Irrigation System: Sprinkler
Power Source: Natural Gas
Well Lift: 100 (ft)
System Pressure: 30 (PSI)
Energy Cost: $5 /MCF

System Modifications

Yes Flow Meter
Yes Irrigation Scheduling
Yes Maintenance & Upgrades

Crop: Corn for grain
Acres irrigated: 240 (acres)
Application: 13 (ac-in/ac)

Seasonal Irrigation System						
Description	Water Use Analysis		Energy Costs Analysis		Pumping Plant Evaluation Added	
	Current Water Use (ac-ft)	Reduction in Water Usage (ac-ft)	Energy Costs ($)	Energy Costs Savings ($)	Energy Costs ($)	Energy Costs Savings ($)
Your System Today	260		$5,760		$4,896	$864

Example Electrical Motor Irrigation Costs

User Input

State: **Oklahoma**
Irrigation System: **Sprinkler**
Power Source: **Electric**
Well Lift: **100 (ft)**
System Pressure: **30 (PSI)**
Energy Cost: **$.11 /KWH**

System Modifications

Yes Flow Meter
Yes Irrigation Scheduling
Yes Maintenance & Upgrades

Crop: **Corn for grain**
Acres irrigated: **240 (acres)**
Application: **13 (ac-in/ac)**

Seasonal Irrigation System						
Description	Water Use Analysis		Energy Costs Analysis		Pumping Plant Evaluation Added	
	Current Water Use (ac-ft)	Reduction in Water Usage (ac-ft)	Energy Costs ($)	Energy Costs Savings ($)	Energy Costs ($)	Energy Costs Savings ($)
Your System Today	260		$8,834		$7,509	$1,325

Example Diesel Engine Irrigation Costs

User Input

State: **Oklahoma**
Irrigation System: **Sprinkler**
Power Source: **Diesel**
Well Lift: **100 (ft)**
System Pressure: **30 (PSI)**
Energy Cost: **$3 /gallon**

System Modifications

Yes Flow Meter
Yes Irrigation Scheduling
Yes Maintenance & Upgrades

Crop: **Corn for grain**
Acres irrigated: **240 (acres)**
Application: **13 (ac-in/ac)**

Seasonal Irrigation System						
Description	Water Use Analysis		Energy Costs Analysis		Pumping Plant Evaluation Added	
	Current Water Use (ac-ft)	Reduction in Water Usage (ac-ft)	Energy Costs ($)	Energy Costs Savings ($)	Energy Costs ($)	Energy Costs Savings ($)
Your System Today	260		$17,053		$14,495	$2,558

Example Propane Engine Irrigation Costs

User Input

State:	**Oklahoma**
Irrigation System:	**Sprinkler**
Power Source:	**Propane**
Well Lift:	**100 (ft)**
System Pressure:	**30 (PSI)**
Energy Cost:	**$2.5 /gallon**

System Modifications

Yes Flow Meter
Yes Irrigation Scheduling
Yes Maintenance & Upgrades

Crop:	**Corn for grain**
Acres irrigated:	**240 (acres)**
Application:	**13 (ac-in/ac)**

Seasonal Irrigation System						
Description	Water Use Analysis		Energy Costs Analysis		Pumping Plant Evaluation Added	
	Current Water Use (ac-ft)	Reduction in Water Usage (ac-ft)	Energy Costs ($)	Energy Costs Savings ($)	Energy Costs ($)	Energy Costs Savings ($)
Your System Today	260		$25,736		$21,875	$3,860

Electric Motor Cost Issues

- Electric motors very efficient (>90%) – but electricity costs more than natural gas fuel (per Btu)
- Learn and understand your electrical rate schedule
- Watch for demand (kW) "Ratchet" charges
- Try to get a rate schedule that does not charge excessively during "off"months (Ratchet Charge)
- High kW demand type charges can push the actual annual cost of electric motor irrigation closer to some fuels
- Call me if you wonder if this is happening and we can go over your situation

Variable Speed or Frequency Drives

- Allows AC motors to be throttled up and down in RPM
- Uses a (feedback) signal such as pressure or flow to automatically control motor
- Keeps electric motor efficiency high even as motor is slowing down and speeding up
- Used for loads that vary over time
  - ✓ End sprayers, additional sprinklers, etc.
  - ✓ Ground water levels vary
  - ✓ Elevations changes
  - ✓ Multiple pivots on one pump

- Functions as a soft-start also
- Some VFD's can convert single to three phase power

Diesel and Fuel Internal Combustion Engines

- Not very efficient (<30%) – but fuel is cheaper than electricity
- These machines tend to be much more susceptible to maintenance neglect and age issues than electric motors
- Must do regular maintenance and servicing as one would with a tractor or truck
- Engine efficiency can rapidly drop by 10-20%, or more, due to lack of maintenance
- This would show up as a direct 10-20% increase in annual costs
- Engines are sometimes run at incorrect higher RPM or loading than rated specs – this will shorten life and drive up fuel usage

Pumping Plant Performance Test

- Determine Pump Discharge Flow Rate (Q)
- Determine pump discharge pressure
- Determine the "Lift", or head, in feet from center of pump impeller to water level down-hole at drawdown
- Determine total Head (TH) = lift + discharge pressure
- Determine pump RPM
- Time during test (hours)
- Calculate "Water-Horsepower" (WHP) = (Q x TH) ÷ 3960
- **Pumping Plant Perf = (WHP x Time) ÷ Gallons Fuel Used = WHP x hr/gal**
- **" " Electric = (WHP x Time) ÷ kWh = WHP x hr/kwh**

Typical Values of Overall Efficiency for Representative Pumping Plants (Everything) Expressed as Percent

Power Source	Maximum Theoretical	Recommended as Acceptable (NPC)	Avg Values from Field Tests
Electric	72-77	65	45 – 55
Diesel	20 – 25	18	13 – 15
Natural Gas	18 – 24	15 – 18	9 – 13
Butane, Propane	18 – 24	15 – 18	9 – 13
Gasoline	18 – 23	14 – 16	9 – 12

Diesel fuel required for acre-inch at head and pressure at about 23% overall efficiency (100% possible)

(Martin et. al.)

Gallons of diesel fuel required to pump an acre-inch at a performance rating of 100%.

Lift feet	Pressure at Pump Discharge, psi 10	20	30	40	50	60	80
0	0.21	0.42	0.63	0.84	1.05	1.26	1.69
25	0.44	0.65	0.86	1.07	1.28	1.49	1.91
50	0.67	0.88	1.09	1.30	1.51	1.72	2.14
75	0.89	1.11	1.32	1.53	1.74	1.95	2.37
100	1.12	1.33	1.54	1.75	1.97	2.18	2.60
125	1.35	1.56	1.77	1.98	2.19	2.40	2.83
150	1.58	1.79	2.00	2.21	2.42	**2.63**	3.05
200	2.03	2.25	2.46	2.67	2.88	3.09	3.51
250	2.49	2.70	2.91	3.12	3.33	3.54	3.97
300	2.95	3.16	3.37	3.58	3.79	4.00	4.42
350	3.40	3.61	3.82	4.03	4.25	4.46	4.88
400	3.86	4.07	4.28	4.49	4.70	4.91	5.33

Conversions factors for other energy sources.

Energy Source	Units	Multiplier
Diesel	gallons	1.00
Electricity	kilowatt-hours	14.12
Propane	gallons	1.814
Gasoline	gallons	1.443
Natural Gas	1000 cubic feet	0.2026

What if your system measures 70% of NPC rating?

- Take the fuel required at 100% NPC from top chart on previous page
- Divide 100% by 70% = 1.42
- Multiply your fuel usage rate (say 2.63 gal per acre-inch x 1.42) = 3.76 gallons per acre-inch
- The difference between the two is the additional fuel you are using above top performance = 3.76 – 2.63 = 1.13 gallons per acre-inch
- So, if the diesel pump system could be improved up to an achievable 100% NPC one could save 1.13 gallons of diesel per acre-inch
- And so on…

System Problems Besides the Driver and Pump

- The pipeline is valved-back at the well to meet pressure requirements (pump pressure is too high);
- Well screen is plugged due to mineral incrustation and/or iron bacteria resulting in extra pumping lift;
- Worn pump impeller due to wear from pumping sand or extended use;
- Improper impeller adjustment on deep well turbine pumps;
- Alteration of the irrigation application system without redesigning the pumping plant;
- Mismatched system components such power unit too large or too small;
- Improperly sized discharge column

References

- https://www.ksre.ksu.edu/irrigate/OOW/P11/Kranz11a.pdf
- http://extension.uga.edu/publications/detail.cfm?number=B837
- http://extension.uga.edu/publications/detail.cfm?number=C965
- EVALUATING ENERGY USE FOR PUMPING IRRIGATION WATER, 2011, Derrel L. Martin, Tom W. Dorn, Steve R. Melvin, Alan J. Corr, William L. Kranz, *Proceedings of the 23rd Annual Central Plains Irrigation Conference, Burlington, CO., February 22-23, 2011*