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Wireless Sensor for Measuring Pump Efficiency

Small Business Voucher Project with KCF Technologies

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Energy and Transportation Science Division

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Abstract

This document is to fulfill the final report requirements for the Small Business Voucher (SBV) CRADA project with ORNL and KCF Technologies (CRADA/NFE-16-06133). Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in many industrial and building power plants. [1] The energy cost is the largest element in the total cost of owning a pump (~40%). In response to a recent DOE mandate for improved pump efficiency pump manufacturers are preparing for the changes that the impending regulations will bring, including design improvements. This mandate also establishes a need for new low cost pump efficiency measurement systems. The standard industry definition of pump efficiency is the mechanical water horsepower delivered divided by the electrical horsepower input to the motor. KCF Technologies has developed a new sensor measurement technique to estimate fluid pump efficiency using a thermodynamic approach. KCF Technologies applied for a SBV grant with ORNL as the research partner. KCF needed a research partner with the proper facilities to demonstrate the efficacy of its wireless sensor unit for measuring pump efficiency. The ORNL Building Technologies Research and Integration Center (BTRIC) test resources were used to test and demonstrate the successful measurement of pump efficiency with the KCF sensor technology. KCF is now working on next steps to commercialize this sensing technology.

Statement of Objectives

The purpose of this CRADA was to facilitate the deployment and demonstration of KCF Technologies' cost effective, wireless sensor technology for measuring pump efficiency. The standard industry definition of pump efficiency is the mechanical water horsepower delivered divided by the electrical horsepower input to the motor. KCF needed a partner with the proper facilities to demonstrate the efficacy of its wireless sensor unit for measuring pump efficiency. The ORNL BTRIC test resources offered a strong alignment for this demonstration activity. KCF's monitoring technology will play a major role in providing our nations pump manufacturers and end-users with an affordable measurement method to assess pump efficiency to aid in improved energy performance.

Benefits to the Funding DOE Office's Mission

Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in many industrial and building power plants. [1] The energy cost is the largest element in the total cost of owning a pump (~40%). Since it is known that the average pump typically operates at efficiencies well below 50%, obviously there is a great need for improving energy efficiency in pump operations. In response to a recent DOE mandate for improved pump efficiency pump manufacturers are preparing for the changes that the impending regulations will bring, including design improvements. The DOE intends to adopt a Minimum Efficiency Index (MEI) that is central to existing European Union (EU) standards.[2] To comply with this new, more stringent standard, pump manufacturers will need access to a certified test facility on which to measure the efficiency over the full range of their pump selections. The approximate cost of installing a certified test facility is in the range of $1M. Of the 450 pump companies in the U. S., only the largest manufacturers own such a facility. The rest must use expensive commercial testing facilities for certified performance testing. For example, testing a 25hp pump / motor in a state-of-the-art test loop costs between $5k~$7k. This situation places the smaller businesses at a huge cost-competitive disadvantage.

KCF already offers an innovative, wireless, predictive maintenance system for pumps, motors and other rotating industrial and commercial equipment. The KCF SmartDiagnostics® vibration monitoring system was designed from the outset as an affordable, integrated suite of products that puts predictive maintenance within practical reach of medium and small operations – for use by anyone demanding the best protection and longest life from key machinery. Their wireless sensors measure a machine's vibration, temperature and pressure. Data is transmitted remotely (e.g., via cell phone towers) to sentry locations where engineers/technicians trained in condition-based maintenance methodologies can assess the state of a machine's health and recommend corrective actions where needed.

KCF's initiative to wirelessly measure motor/pump efficiency in real time with an affordable technology addresses the industry need for pump efficiency measurement and characterization. The legacy pump efficiency approach requires measurements of the electric power consumption, fluid pressure, and fluid flow which can cost $20k per pump. A fully installed KCF wireless measurement system will cost in the range of $2k ~ $3k. Also, because it is portable, the measurement system can be moved easily from one pump set-up to another, thus saving on personnel and installation costs.

KCF will leverage this demonstration testing with ORNL to commercialize an economical wireless sensor system for monitoring pump efficiency to enable manufacturing energy conservation efforts. The pump efficiency monitoring capability will nicely complement KCF's family of sensors that make up their commercial market. Adding the new efficiency sensor to KCF's existing suite of diagnostic sensors is straightforward since the associated wireless firmware and software is mature. The pump efficiency sensor unit will be integrated into KCF's wireless protocol and data analysis routines without major changes. This added monitoring tool would greatly enhance KCF's ability to remotely monitor not only the health of a pumping system, but also the operating efficiency that is critical to energy savings. This type of monitoring will help industry reduce energy costs and consequently, have a positive impact on our environment by reducing carbon emissions.

Technical Discussion of Work Performed by All Parties

The scope of work can be summarized as ORNL collaborating with KCF to deploy the KCF pump efficiency sensor technology on the Flexible Research Platform (FRP) #2 Ground Source Heat Pump (GSHP) system to demonstrate the KCF technology. The FRP#2 GSHP system has a 1.5 HP, 30 GPM water pump system that was suitable for this initial validation testing.

The KCF sensor system consists of a probe that measures temperature and pressure (Figure 1). The probe measurement is provided wirelessly to the KCF SmartDiagnostic primary receiver node and collection server. The probes are inserted into the flow stream before and after the pump and perform very accurate temperature and pressure measurements to measure the work done on the fluid by the pump. A cellular modem will be used to enable remote monitoring and data retrieval via the internet. The new KCF efficiency calculation method uses a thermodynamic approach that requires very precise pressure and temperature gradients $(\Delta P, \Delta T)$ $and\ knowledge\ of$ the fluid density, rho and specific heat, Cp on the inlet and outlet of the pump (See Equation in Figure 2). Legacy approaches require various measurements such as fluid measurements of pressure and flow and motor power measurements that are more expensive, more intrusive, and are not suitable for integration into a pump system.

Figure 1. Sensor Probe

$$Efficiency = \frac{\frac{\Delta P}{\rho}}{\frac{\Delta P}{\rho} + C_p \Delta T}$$

Figure 2. Equation for Thermodynamic Pump Efficiency Calculation

The project kickoff occurred on April 19, 2016 with Gary Koopman from KCF Technologies, Taifur Rahman from Xylem, and the ORNL team. The ORNL team was led by David Fugate and included Xiaobing Liu and Tony Gehl. Xiaobing Liu is the contact for ORNL research water loops and Tony Gehl is the instrumentation. The kickoff meeting included discussions about the project scope, technical details, tours of the ORNL test facilities, and sensor research.

After the kickoff meeting, ORNL modified the FRP#2 GSHP water flow system to support the installation of the KCF pump efficiency probes (Figure 3). The FRP#2 instrumentation system was updated to provide specific measurements for pump efficiency validation measurements.

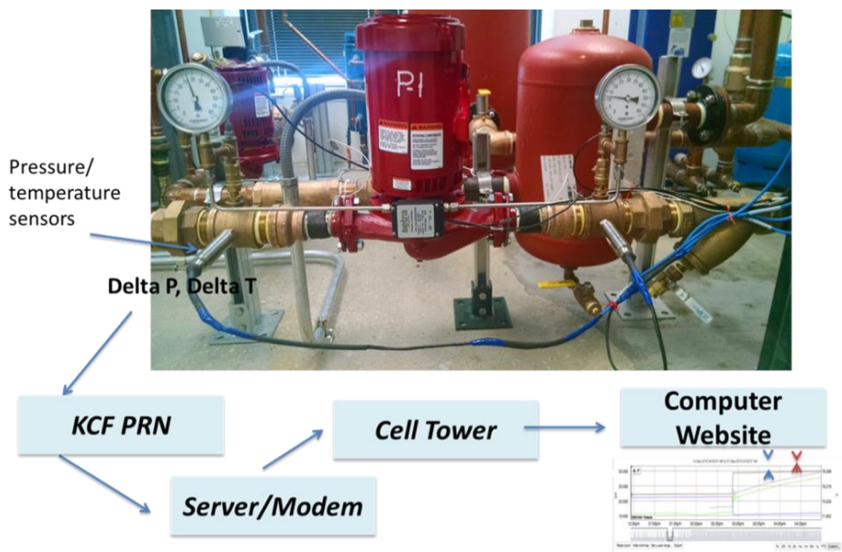

Figure 3. Photograph of the FRP#2 GSHP System with KCF Probes Installed

Test and validation of the KCF pump efficiency probe systems began in September 2016. The KCF measurements were transmitted via cell modem to the KCF office for collection. The ORNL instrumentation measurements were collected locally and shared with KCF for validation purposes. After some initial verification and validation of the ORNL instrumentation and selection of the desired operating points for the pump system, the KCF efficiency measurement was compared to legacy measurements.

The different operating test points using the FRP#2 GSHP water loop and the legacy method efficiency calculation results are shown in Table 1. The legacy method required the measurement of differential pressure (delta psi), flow, and power consumption. In these tests, the pump ran at its full speed (3600 RPM) and the system water flow was adjusted by closing/opening the shutoff valve in each of the parallel loop of the experimental hydraulic pumping system. Each test condition was maintained for at least 30 minutes to eliminate the transient effect on pump efficiency measurement when changing the operation conditions. These test conditions are shown graphically in Figure 4. Both the KCF test results and the ORNL legacy test results were validated with the pump manufacturer data with an example shown in Figure 5.

The pump efficiency using a legacy approach calculation (legacy approach measurements-based) was compared to the KCF Technologies sensor approach. The legacy approach required the measurement of differential pressure (delta psi), flow, and power consumption. Table 2 summarizes the comparison for specific test conditions. The KCF Technologies sensor pump efficiency approach demonstrates a median difference of 1.6% over the five test conditions with the largest difference of -8%.

Table 1. FRP#2 GSHP Water Loop Test Summary Table with Legacy Method Efficiency Calculation in Red Font

Measurements			**Input**	**Results**		
Delta P	Flow	VFD Power input	Elec_Eff	Pump work	Pump_Eff	delta T
(ft)	(GPM)	(W)	(-)	(W)	(%)	(F)
83.6	54.5	1,603.19	0.815	857.89	**65.7**	0.056
87.1	47.5	1,451.88	0.815	779.63	**65.9**	0.058
91.0	39.0	1,297.88	0.815	667.36	**63.1**	0.068
94.0	16.5	876.25	0.815	292.55	**41.0**	0.174
94.5	16.5	878.45	0.815	293.47	**41.0**	0.175
94.3	16.5	883.08	0.815	293.56	**40.8**	0.176
91.0	37.8	1,301.81	0.815	647.55	**61.0**	0.075
88.0	44.9	1,429.07	0.815	744.42	**63.9**	0.064
83.3	54.9	1,598.49	0.815	861.36	**66.1**	0.055
94.6	17.3	883.47	0.815	308.89	**42.9**	0.162

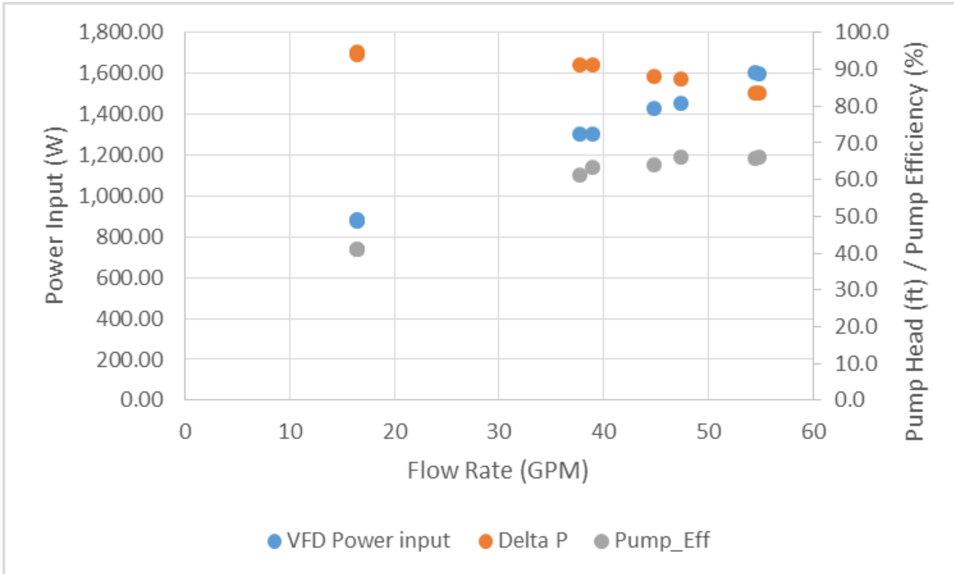

Figure 4. Test Summary Pump Power Inputs, Pump Head Pressure, and Pump Efficiency at Various System Flow Rates

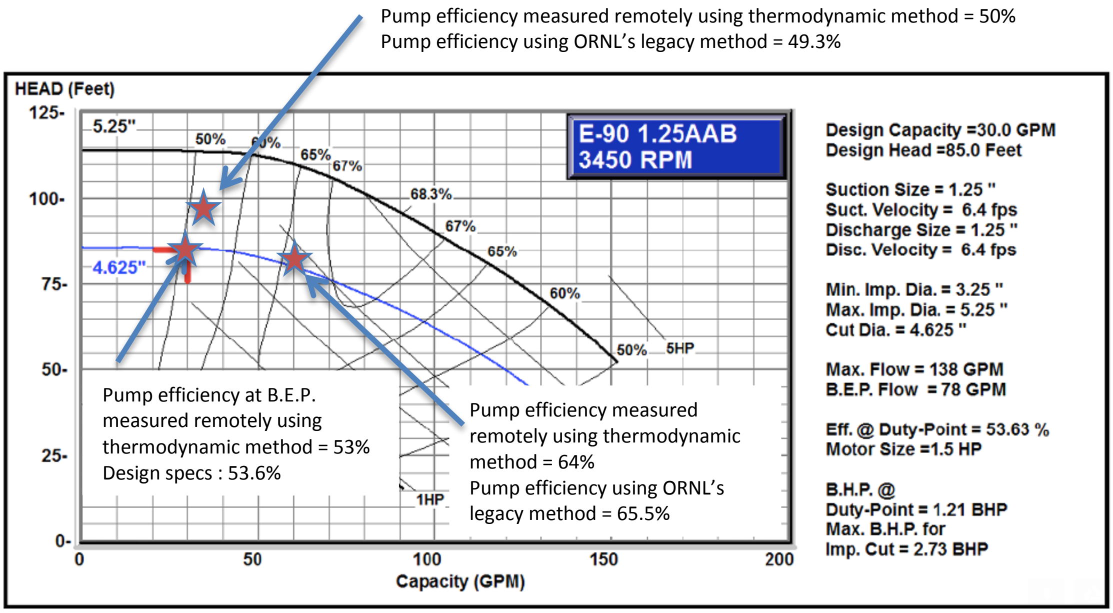

Figure 5. Comparison of KCF Measurements and ORNL Pump Efficiency Measurements versus Pump Manufacturer Performance Data with Two Operating Points Away from Base Operating Point Flow Conditions

Table 2. Comparison or Legacy Efficiency Measurements versus KCF Technology Sensor Approach

Test conditions	Measurements			Input	Results (ORNL)			Measurement and result (KCF)				
	Delta P	Flow	Power in	Elec_Eff	Pump work	Pump_Eff	delta T	delta P	delta T	E_h	E_m	Pump_Eff
	(ft)	(GPM)	(W)	(-)	(W)	(-)	(F)	(ft)	(F)	(-)	(-)	(%)
1	83.6	54.5	1,603.19	0.815	857.89	0.66	0.056	79.7	0.033	238.9741	378.3408	0.63
2	94.3	16.5	883.08	0.815	293.56	0.41	0.176	93.6	0.111	281.2126	745.7682	0.38
3	91.0	37.8	1,301.81	0.815	647.55	0.61	0.075	89.6	0.034	269.1042	410.7936	0.66
4	88.0	44.9	1,429.07	0.815	744.42	0.64	0.064	87.1	0.037	261.4795	417.1056	0.63
5	83.3	54.9	1,598.49	0.815	861.36	0.66	0.055	82.1	0.031	246.668	376.7435	0.65

Subject Inventions
No Subject Inventions were determined.

Commercialization Possibilities
KCF Technologies is pursuing multiple steps to progress to commercialization. KCF with Penn State as a subcontractor has additional funding from Intel to integrate Internet of Things (IOT) technology with the pump flow efficiency measurements. KCF is planning to integrate the sensor, sensor measurement electronics, and wireless communication into a device that can be either added to a pump in the field or integrated directly into the pump during manufacturing. KCF is discussing sensor testing with the pump manufacturer Xylem at their Seneca Falls, NY facility.

Plans for Future Collaboration
KCF is conducting discussions with ORNL staff on measurement techniques, sensing electronics, and data acquisition to improve the accuracy and robustness of the pump efficiency measurement technique. KCF and ORNL are also discussion opportunities for further testing of the sensing technology on ORNL facility assets for larger flow systems such as chillers.

Conclusions
The new sensors developed by KCF Technologies for measuring pump flow were successfully installed, tested, and demonstrated on the Flexible Research Platform (FRP) #2 Ground Source Heat Pump (GSHP) system at ORNL. The testing indicated that the new sensing method could estimate the pump fluid efficiency. The KCF Technologies sensor pump efficiency approach demonstrates differences from the legacy approach within +/-5% and a median difference of 2%.

Acknowledgements
This project with KCF Technologies to test and demonstrate the new sensing technology was sponsored by the DOE SBV program. The ORNL Technology Transfer Office and the ORNL Building Technologies Research and Integration Center provided key support, infrastructure and resources for this activity.

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[1] Hydraulic Institute, Europump, and the US Department of Energy's Office of Industrial Technologies (OIT), Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems, DOE/GO-102001-1190, January 2001.

[2] U.S. Department of Energy, Energy Conservation Standards for Circulator Pumps, Regulations.gov, https://www.regulations.gov/docket?D=EERE-2016-BT-STD-0004