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Online Pump Efficiency

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ONLINE PUMP EFFICIENCY

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Modeling Pump Efficiency Automation

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ABSTRACT

Knowing the efficiency of a pumping unit has important operational and financial benefits to those who operate the unit. Historically efficiency is collected on a periodic basis through on-site collection of the necessary parameters. Unit efficiency can be calculated on a real time basis by combining telemetered data with fluid properties in a Real Time Transient Model (RTTM). This method however needs to be validated in order to ensure it is equivalent to field efficiency testing.

The RTTM was expanded to be able to calculate unit efficiency utilizing telemetered data and modeled fluid properties. Three crude oil and two refined products units were configured in the model to perform the calculations. Data from each of the units was stored in a relational database for later analysis. Date and time, efficiency ratio (current efficiency/manufacturer's efficiency), flow rate and viscosity were stored once every fifteen minute. Field efficiency test data was retrieved and then compared to the telemetered data. A deviation of one percent or less was considered acceptable.

Where the two methods did not correlate within the required one percent, the data was analyzed to determine the root cause. Errors in the model's algorithms and potential errors in field data collection account for all departures. This research supports the use of the RTTM to calculate unit efficiency.

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CHAPTER 1

The Problem

Introduction

One of the major costs in operating a petroleum pipeline is the power to run a pumping unit. [Bain, 2005]. A pumping unit, often referred to simply as a unit, consists of a pump and its associated motor. Great effort goes in to the design of the unit and pipeline combination to achieve the most efficient operation possible.

Once the unit is in place, continued operation of the unit can degrade its efficiency, primarily through mechanical wear in the pump. Knowing the degree of efficiency degradation allows the pipeline operator to schedule the unit to be rebuilt back to its original efficiency, helping to reduce power consumption and thus cost. Historically this performance is monitored by a team which sets up on site to manually measure efficiency with specialized instrumentation [PES, 2009]. Figure 1 shows a 2000 horsepower unit being tested manually [ProPump, 2011].

Automating this manual process could allow more rapid detection of worn pumps as well as eliminate the cost of manual testing. This increased efficiency could result in lower operating cost to the pipeline owner.

Photograph courtesy of ProPump



Figure 1. Example of pump being tested.

General Statement of the Problem

While the calculations for field testing are not complex, the coordination and manpower necessary to perform manual efficiency testing on a pipeline system in a large geographical area can be significant. For this reason manual monitoring is only performed occasionally on selected units.

The person(s) performing field testing must ensure that the unit is running and is not scheduled to be turned off during the test. In some cases they must coordinate the start of the unit and wait for the unit to warm up and then have it shut down after the test if it is not needed.

They must also know what product is being pumped based on the pipeline's schedule. Since most lines are batched, any batch interface must be significantly far from the unit to ensure that the product in the unit is known. Unit suction and discharge pressure are measured along with power to the motor. The pipeline must be running at steady state to ensure that the flow rate through the unit is equal to that of the influent flow meter. With all this one point can be calculated for a specific product, flow rate and time.

The instruments necessary to do efficiency calculations on a continual basis, which are pump suction and discharge pressure along with motor power consumption have been telemetered to a central control center for many years. The major element that has been missing is the properties of the fluid in the unit on a real time basis. Installing enough sensors at each pump to obtain these properties, along with maintaining the sensors, is not generally justifiable.

Potential Solution

Real Time Transient Modeling (RTTM) has in recent years been implemented on pipelines for the primary purpose of detecting leaks in the pipeline [Telvent, 2011]. This modeling necessarily tracks the properties of the fluid along the length of the pipeline and inherently in the unit itself. Combining modeled information with telemetered data would supply the data necessary to implement real time efficiency calculation. This combination could eliminate the manual testing that takes place today and enable continuous monitoring for units that are running inefficiently and thus due for rebuilding.

Statement of the Hypothesis

Unit efficiency data calculated by combining telemetered data and modeled fluid properties are within one percent of the value collected using manual efficiency tests performed onsite.

Delimitations

Only units that already had sufficient instrumentation telemetered to a central control center were examined. The unit also had to have been modeled within the RTTM, which was enhanced to perform the calculations.

Limitations

The study was limited to Newtonian fluids due to the fact that the equations for efficiency are generally not accurate with high viscosity fluids. The temperature rise method of calculating efficiency was not included in this study.

CHAPTER 2

Review of the Related Literature

Optimization and Maintenance

Process optimization and maintenance is a relatively new task for data acquisition systems. The prime reason for data acquisition systems has been to present to the user operational data necessary to control the process. According to Mark Taft “Integrating the electrical equipment in a plant to the process automation systems is the next frontier in delivering productivity improvements” [Taft 2009]. Rising energy costs and increased pressure to reduce them are driving performance improvement.

Even more recently simulators are being integrated with data acquisition system to perform more complex calculations. Jim Montague states that “Process simulations are bursting their former boundaries and storming into optimization, model-predictive control, abnormal situation management and closing in on real-time operations” [Montague 2010].

The Method in Reverse

While modeling is often used in engineering design to simulate a pumping system, errors in the modeling of existing system can be attributed to using the manufacturer’s pump curve instead of the actual efficiency curve. In an attempt to model a city water system the Monroe County Water Authority (MCWA) in Rochester, N.Y [Verosky, 2009] found they could not match the system performance because of pump efficiency degradation.

While their solution was to rebuild the pumps to restore total model fidelity, a different paradigm would be to combine real time data with the model to calculate each pump's actual efficiency and only rebuild those falling below a defined threshold. Live data could be used to compare pumping system performance with the theoretical manufacturers curve to determine when a pump is worn sufficiently to justify rebuilding.

Efficiency in Water Systems

Pump efficiency testing is very common in irrigation applications. These irrigation pump tests are performed on a periodic basis when requested by the owner. Even these occasional tests can be cost prohibitive, which has spurred government agencies and utility companies to find ways to defer the cost to the owner in order to find worn pumps and replace them [Agricultural Pump Efficiency Program, 2009]. Finding it difficult to justify a periodic test, these operators cannot justify installing and maintaining a dedicated communication and data acquisition system to perform the calculations in real time.

The calculations for pump efficiency are relatively simple and web based calculators such as the one provided by Pumps and Systems Magazine [Pumps, 2009] makes the calculation trivial. The required inputs are flow rate, discharge pressure, suction pressure, motor efficiency and electrical power. This calculator was designed primarily for use in water pump operation and assumes that no corrections for fluid properties is required, which is not the case when pumping petroleum products.

Elements for Real Time Calculations

In the case of petroleum pipeline operations a Supervisory Control and Data Acquisition (SCADA) system is commonly installed to operate and monitor remote stations from a central location [NTSB, 2005]. The monitoring system often retrieves some, if not all, values needed for pump efficiency testing. Those instruments not already available can be added to the existing infrastructure.

RTTM's, which need to track fluid temperature, necessarily need efficiency to determine fluid temperature rise across the pump. This is commonly calculated by using the pump efficiency from the manufacturer's curve. A typical curve shows efficiency as a function of head and flow. A pump efficiency curve, along with horsepower and head curves, generalized to remove the engineering units, is shown in figure 2 [Goulds Pumps, 2009].

Diagram courtesy of Gould Pumps

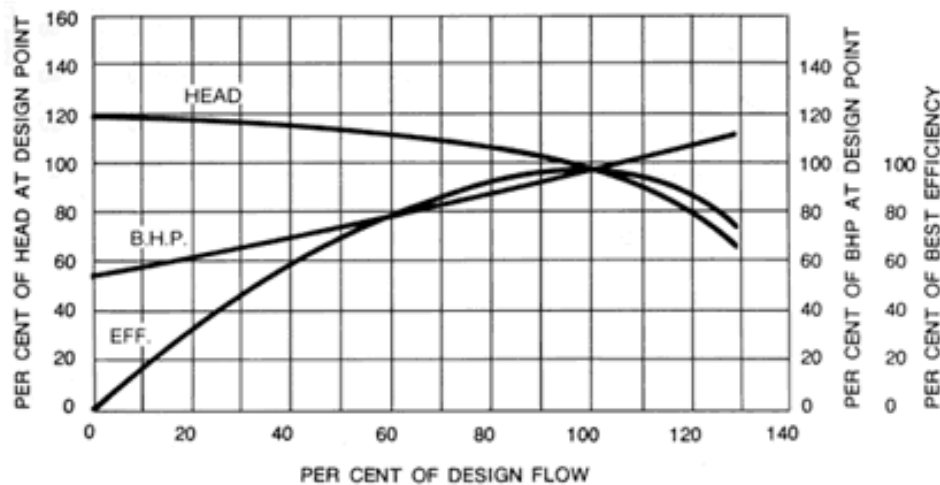


Figure 2. Pump efficiency curve example.

In order to take advantage of the efficiency curve, a fourth order fit is applied to it to get an equation for flow versus efficiency to obtain efficiency at the current flow rate. Equation 1 shows an example of the RTTM's equation for pump efficiency.

$$\text{kenounu02_ef} = \text{kenounu02_kef}(1) + t_l\text{volfl} * (\text{kenounu02_kef}(2) + t_l\text{volfl} * (\text{kenounu02_kef}(3) + t_l\text{volfl} * \text{kenounu02_kef}(4))) \quad (1)$$

In this equation kenounu02 is the tag name for the pumping unit. Various parameter names are built on this tag name. The parameter kenounu02_ef is the calculated efficiency, while kenounu02_kef(n) are the constants in the fourth order curve fit. T_lvolfl is a temporary volume flow variable that compensates for the density of the fluid. This is necessary because the manufacturer's curve was generated using water as the fluid.

The basic equation for efficiency that can be used for real time calculations can be derived as shown in equation 2 [Heald, 1998].

$$\begin{aligned} & \text{Efficiency} \\ &= \frac{\text{Flow} \times (\text{discharge pressure} - \text{suction pressure})}{1.141485 \times \text{motor efficiency} \times \text{electrical power}} \end{aligned} \quad (2)$$

The flow variable also needs to account for the volume flow, as in the previous equation, to compensate for fluid properties. Once these two efficiencies are known, comparisons can be made between them to determine live performance degradation.

A ratio of the two efficiencies with telemetered efficiency divided by manufacturer's efficiency would provide an efficiency ratio that shows how far the current efficiency departs from the manufacturer's baseline. This parameter would also be easier to evaluate because its magnitude would not be a strong function of flow rate.

Summary of the State of the Art

The literature suggests that while all the elements that could be used to perform real-time efficiency testing are readily available, these elements have not been combined, and proven to be a viable method, to replace manual testing. Given the prominence of modeling in design and the trend toward their use in real time, it would seem logical to take this step to verify the model's ability to supply the necessary data and algorithms.

CHAPTER 3

Research Procedure

Overview

The RTTM as a tool is used primarily to detect leaks in the pipeline. In order to do this accurately, the model is calculating hundreds of parameters every second. These parameters can be utilized in aspects other than leak detection. Online pump efficiency calculation is one possible area where the modeled parameters were applied.

Model Expansion

In order to calculate thermal and pressure effects induced by the unit, the RTTM uses manufacturers curve data to calculate pump properties. While this yields efficiency of a newly installed pump under ideal circumstances it is seldom accurate in operational units. With sufficient telemetered data combined with modeled data, calculation of actual pump efficiency was made possible. This required model expansion to implement live efficiency calculations. Equation 2 was added to the model to calculate current efficiency along with the existing Equation 1 which calculated the manufacturer's efficiency. This not only improved the model but also allowed calculation of the desired pump efficiency in real time.

Once the efficiency was calculated the following parameters were stored in a relational database for later analysis;

- 1) Date and time
- 2) Efficiency ratio (current efficiency/manufacturer's efficiency) (%)
- 3) Flow rate through the unit (BPH)
- 4) Viscosity of the fluid (cst)

Potential Uncertainties

While the online pump efficiency testing would seem simple, reality seldom matches theory. Several issues could complicate the calculations needed to determine a single factor that would represent pump wear. The uncertainties in the calculations need to be considered and accounted for.

Batch Tracking. Volume flow rate corrected to standard conditions require fluid properties. Fluid properties rely on batch tracking algorithms which determine the location of a batch in the line. The batch head and tail location is only known at the pipe inlet, with every other point tracked in the simulation model. Batches are sent serially through the pipeline, each batch with differing fluid properties. Uncertainties in the location of the batch interface between the batches can give erroneous results, using fluid properties for one batch, when in reality a different batch may actually be going through the unit.

Batch Properties. Fluids pumped in the line are assigned a fluid type. For example a type may be Jet Fuel or Ultra Low Sulphur Diesel. The properties of these refined products do not generally vary significantly, because they are tightly controlled by the refinery. Crude oil is also pumped to the refinery in other pipelines. While crude oil batches are also categorized into crude types, these batches have more widely varying fluid properties from one batch to another, which can affect the calculated efficiency.

Flow Rate. Flow rate through the unit is not always available at the unit. Pipeline inlet flow is available at the first station but subsequent station flow must be calculated by the model based on mass balance principles. Uncertainty in this parameter can further complicate derivation of actual unit efficiency.

High Viscosity Crude Oil. The manufacturers pump curve was generated with water as the fluid in the pump. Standard compensations for viscosity work well for Newtonian fluids. When the crude oil becomes excessively viscous the correlations do not predict efficiency well. When these types of heavy crude oils are being pumped the data was ignored.

Approach

With the model expansion and data retention discussed above, a set of values were available for each unit being tested. Variables were stored at 15 minute intervals. Three units pumping crude oil and two units pumping refined products were studied. Once sufficient data was stored over time analysis was performed on this data to be able to remove outliers and to characterize the variables to reduce the uncertainties discussed above.

As shown in Figure 1, efficiency is a function of flow rate. Evaluating efficiency as a function of time would result in large differences in efficiency due to flow rate variance. The data was stored as an efficiency ratio (current efficiency/manufacturer's efficiency) to give a value that is baselined from a new pump condition regardless of the flow rate.

The curve in figure 1 was developed with water as the fluid. Fluid viscosity data was utilized to break down the data into an additional dimension of viscosity groups. Modeling uncertainties identified above such as flow rate, batch properties and batch position was evaluated to remove transition points between groups which distort the data..

Manual pump efficiency tests that were performed during the automated data collection interval were then correlated with telemetered values. Comparison was then be made to ensure the method produces results within one percent of any manual tests performed during the same time period.

CHAPTER 4

Presentation of Findings

Overview

Chapter 3 discusses the methods used to collect the data for analysis. This chapter presents the collected data in various forms along with analysis of the data in order to support the hypothesis and show that the method provides a solution to the problem. The statement of the hypothesis was as follows: Unit efficiency data calculated by combining telemetered data and modeled fluid properties are within one percent of the value collected using manual efficiency tests performed onsite.

Raw data

Figure 3 shows the raw data collected for one unit. The trend indicates an obvious offset in values beginning January 2011. During that time a major upgrade to the model was made. Working with the vendor it was discovered that a conversion factor was moved in the code which resulted in double conversion from units of horsepower to KW. This was corrected in the model and then data collection continues with more realistic values beginning in September 2011

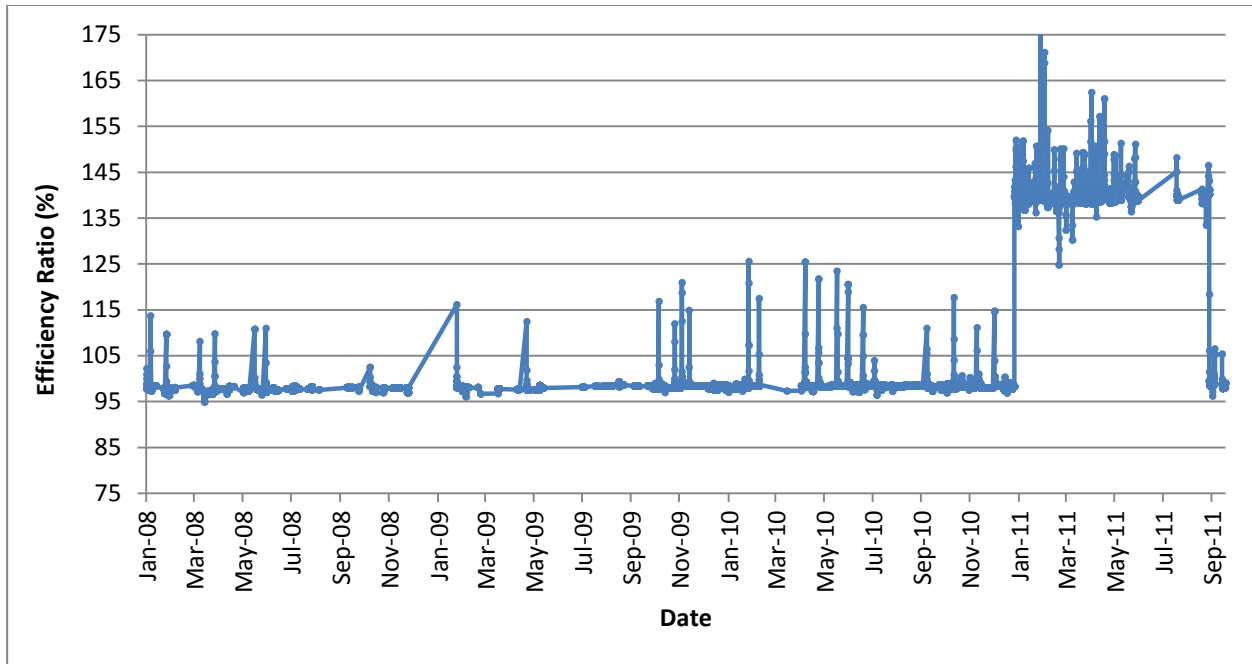


Figure 3. Raw data of one unit's efficiency ratio over time, shows obvious offset in values in January 2011.

Examination of the error showed that the collected historical values were simply offset by the conversion factor. In order to use all the collected values, a rule was created that when the collected efficiency ratio was greater than 128, which is greater than the largest value before the error, then the value was divided by the horsepower to KW factor of 1.41485. Figure 4 shows the corrected raw values after applying this method.

Figure 4 also show obvious spikes in the data to unrealistically high values. These spikes were analyzed and found to be largely from two sources. First the algorithm for pump efficiency caused a spike in the efficiency shortly after the pump starts up. This was resolve by ignoring a fixed number of data points collected after a pump startup. This is in line with field data collection procedures which requires the unit to be warmed up and the pipeline to be at steady state.

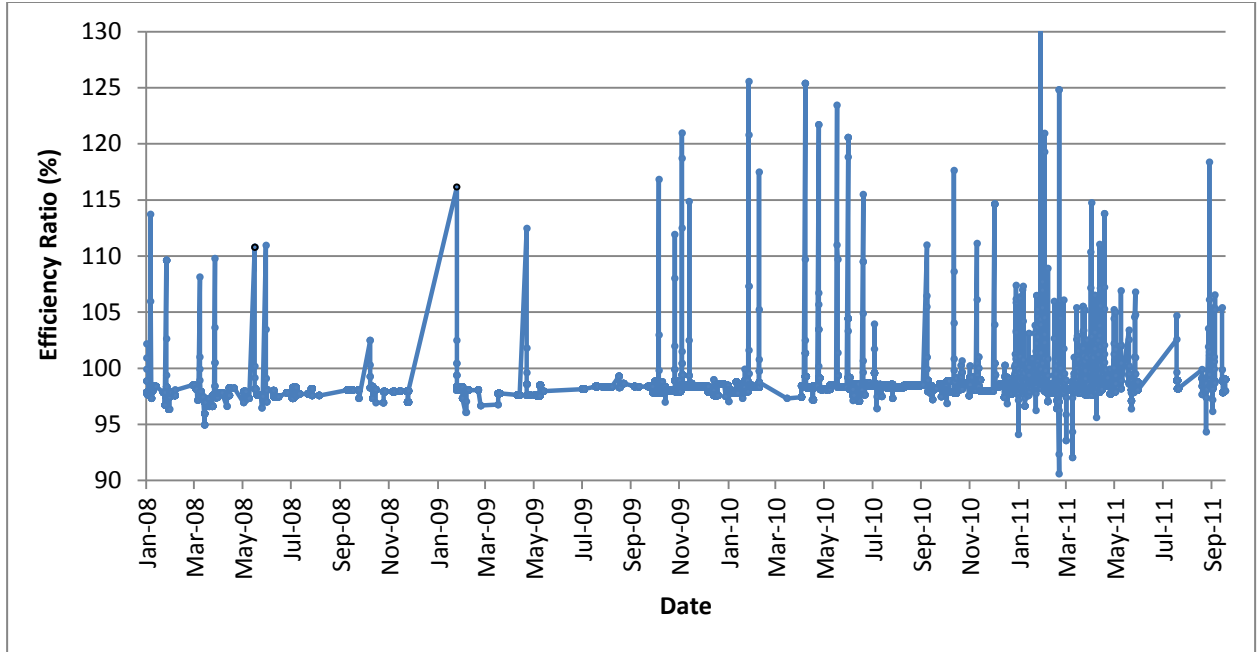


Figure 4. Corrected raw data of one unit's efficiency ratio over time.

The second source of spikes was found to be at a batch interface. This likely due to the uncertainty of batch position in the model as discussed in chapter 3. When the efficiency is calculated based on the properties of what is modeled to be in the unit, but the unit actually has a different product in it, an efficiency spike may result. Removing a fixed number of data points at an interface change resolved this problem. An interface was located by using a significant change in fluid viscosity. Figure 5 shows a graph of the resultant data which no longer exhibits the drastic spikes.

The remaining variations of data in Figure 5 are not actually spikes but entire batches of product pumped through the unit. The compressed time scale of the graph makes them appear to be spikes.

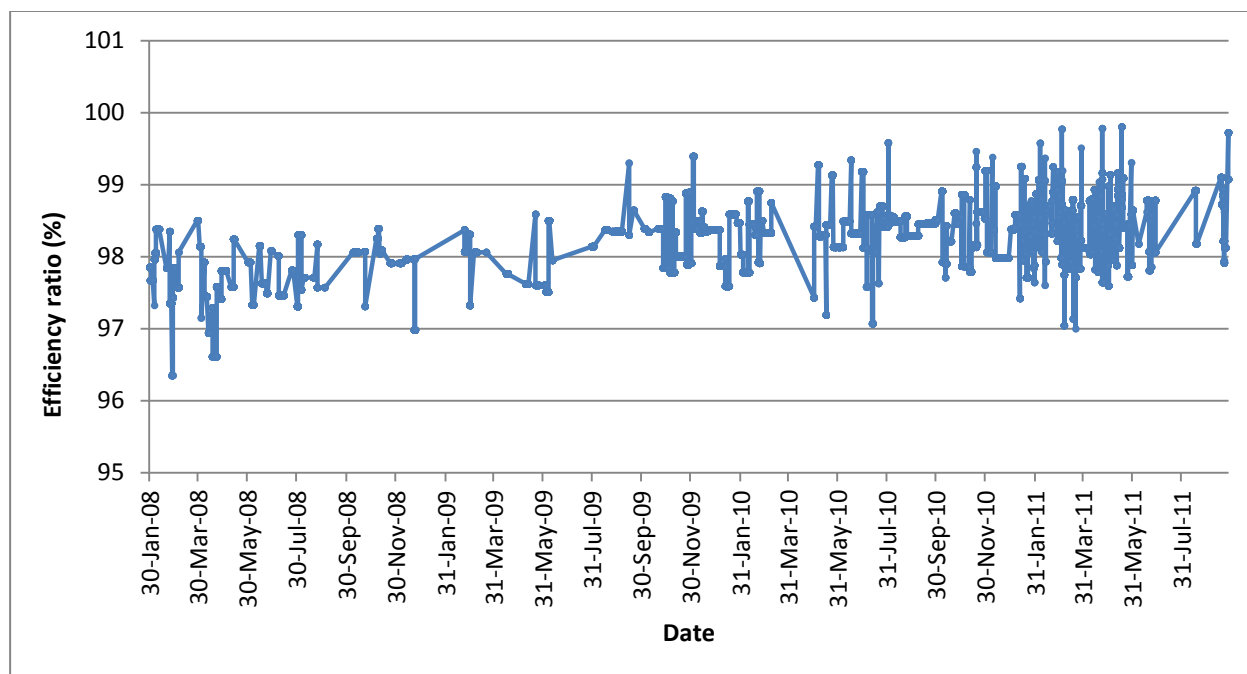


Figure 5. Raw data of one unit's efficiency ratio over time with large unit startup and batch change spikes removed.

Field Data Comparison

With the spikes anomaly resolved a comparison was then made with the collected field efficiency data. Field efficiency tests are generally performed once a year on each unit. The field collected data only indicated a date when it was collected and not time. This omission required further analysis by comparing flow rate and product viscosity data to estimate what time the field value was collected. Some uncertainty was introduced because of the lack of time data on field efficiency.

Table 1 shows the comparison of the three crude oil pumps. To compare with telemetered data, field collected data was also divided by the manufacturer's efficiency to put both in the same units of an efficiency ratio. The delta ratio must be multiplied by the manufacturer's efficiency to calculate the actual delta efficiency for comparison to the

hypothesis's tolerance. As can be seen the correlation between the two methods is within the hypothesis tolerance with a few exceptions which need explanation.

Table 1.

Comparison of field collected crude oil pump efficiency with telemetered values.

Unit	Date	Field Ratio	Telemetered Ratio	Delta Ratio	Delta Efficiency
DLGTUNU01	3/10/2008	94.52	94.22	0.30	0.25 ^a
DLGTUNU01	3/2/2009	88.97	88.12	0.85	0.72
DLGTUNU01	3/15/2011	86.56	92.49	5.92	2.19 ^a
DLGTUNU02	3/10/2008	90.24	90.70	0.46	0.39
DLGTUNU02	3/8/2009	84.87	87.26	2.39	2.07 ^b
DLGTUNU02	3/11/2009	89.96	88.35	1.61	1.40
DLGTUNU02	2/18/2010	89.95	89.68	0.27	0.23
DLGTUNU02	3/4/2011	90.70	90.63	0.07	0.06
DLGTUNU03	3/16/2008	92.19	92.27	0.08	0.06 ^a
DLGTUNU03	3/8/2009	91.89	91.32	0.57	0.49 ^a
DLGTUNU03	3/15/2011	93.75	94.68	0.93	0.79 ^a

Note. All efficiency values are in efficiency ratio (%)

^aNo telemetered data on this date, nearest entry with equivalent flow and viscosity used. ^bField test was repeated three days later with improved results.

DLGTUNU01. The first and last field point for this unit had no entries for the date and time indicated on the field test data. On 3/10/2008 the modeled data did show a short run of the unit on the following day which leads to an assumption that the field date was recorded incorrectly. On 3/15/2011 there was no equivalent value found so data from several days later with somewhat similar flow and viscosity was used. The poor correlation is assumed to be the cause of this mismatch. Figure 6 shows both field and telemetered efficiency for DLGTUNU01.

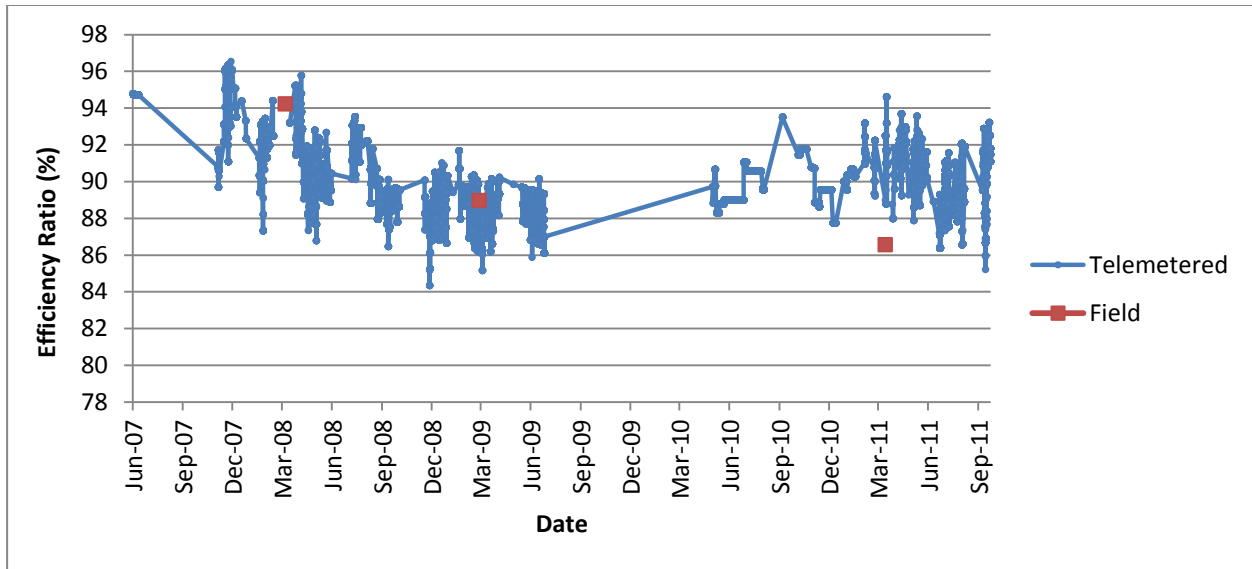


Figure 6. Trend of both telemetered and field efficiency ratio data for DLGTUNU01.

DLGTUNU02. The 3/8/2009 value was drastically lower than previous collected field values, which appears to have given cause for a retest three days later with data that correlates better. Even the retest on 3/11/2009 was just outside the hypothesis limit of one percent. These two field efficiency values are considered to be questionable, or the collection date may be incorrect. Figure 7 shows both field and telemetered efficiency for DLGTUNU02. As can be seen from this figure the efficiency can vary widely over a short period of time. If the date is not correct correlation with telemetered data cannot be assured.

It is also interesting to note that even the assumed bad 3/8/2009 data point that triggered a retest compares favorably to other telemetered points taken at about this time. This assumed bad data point may actually be valid for the batch that was pumped at that time. Having only the field data would make this point appear to not correlate with the other field points.

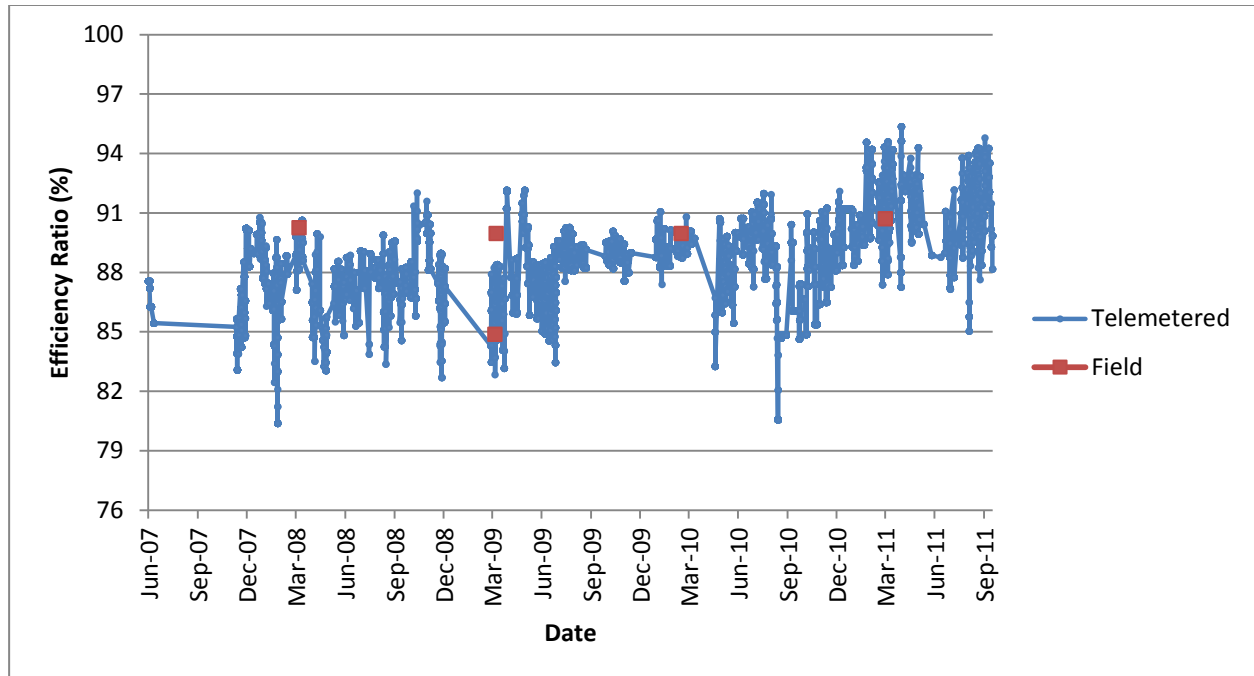


Figure 7. Trend of both telemetered and field efficiency ratio data for DLGTUNU02

DLGTUNU03. This unit is used the least of any of the three units at this station. Because the unit was not already running, it appears to have been started only for a short period during the field efficiency test and then shut down afterwards. None of the field tests at this site correlated with telemetered data on the same day, however similar flow and viscosity values were used on nearby days to use as correlation points. Figure 8 shows both field and telemetered efficiency for DLGTUNU03. Long straight lines between groups of points are when the unit is not used. Both this unit and DLGTUNU01 were not used most of 2010 therefore the annual test was eliminated.

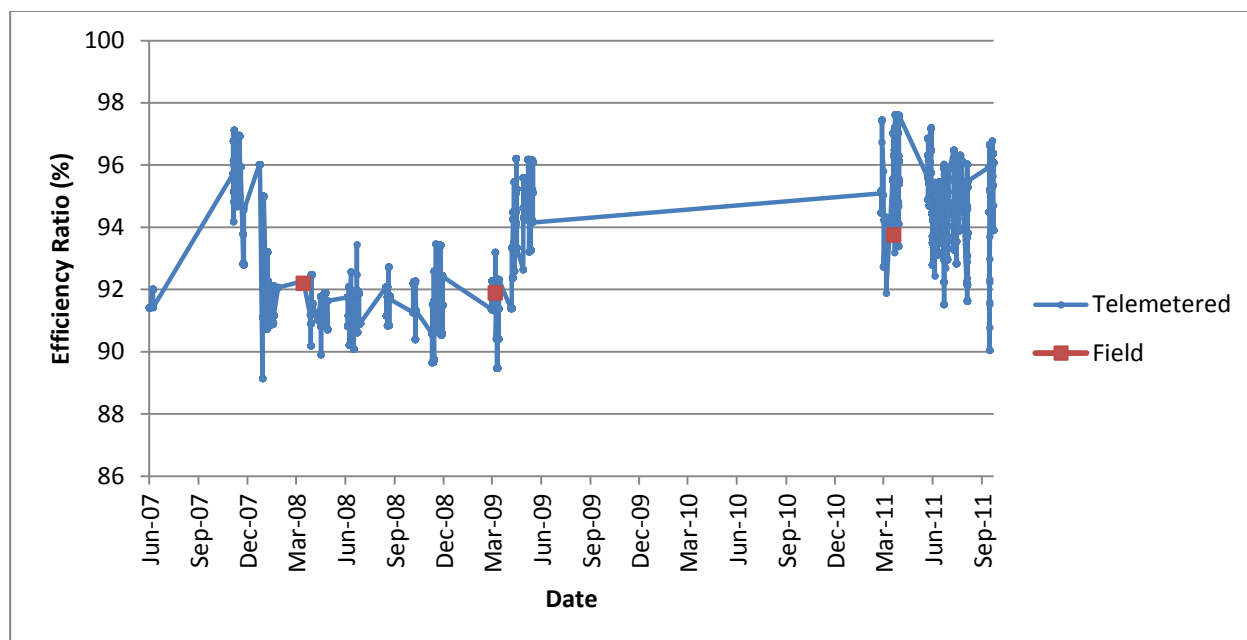


Figure 8. Trend of both telemetered and field efficiency ratio data for DLGTUNU03

Table 2 shows the comparison of the two product units. As with Table 1 field collected data was divided by the manufacturer's efficiency to put both field and telemetered values in units of efficiency ratio. Unlike crude oil, product properties do not vary greatly from one batch to the next, being tightly controlled by the refineries. This should result in even better correlation than with crude oil which varies widely as it undergoes no processing and variations in natural deposits can be significant. With the tighter control of properties correlation was not as good as with crude unit but for different reasons as explained below for each unit.

Table 2.

Comparison of field collected products pump efficiency with telemetered values.

Unit	Date	Field Ratio	Telemetered Ratio	Delta Ratio	Delta Efficiency
KENOUNU01	3/12/2008	93.57	92.69	0.88	0.66
KENOUNU01	3/10/2009	69.45	92.76	23.31	17.12 ^a
KENOUNU01	3/10/2010	86.44	91.52	5.08	3.73 ^b
KENOUNU01	3/18/2011	90.94	104.99	14.05	11.33 ^c
KENOUNU01	3/29/2011	93.66	109.88	16.22	12.10 ^c
KENOUNU02	3/10/2009	96.97	98.06	1.09	0.84
KENOUNU02	3/10/2010	95.08	98.33	3.25	2.58
KENOUNU02	3/8/2011	96.30	97.04	0.74	0.59

Note. All efficiency values are in efficiency ratio (%)

^aExtremely low field collected value, considered to be bad. ^bUnit only run for short time during field data collection. ^cAn error in the telemetered data algorithm for this unit was introduced in an update of the software which affects these data points.

KENOUNU01. The 3/10/2009 field test value appears to be unrealistically low, which calls in to question the validity of the collected data. The field test on 3/10/2010 the unit was only run for a short period of time which likely affected both field and telemetered data. Even this field point appears to be too low.

Both telemetered data points on KENOUNU01 in 2011 were unusually high. Closer examination of the algorithm which calculates this value revealed that an error in the routine causes it to only calculate when there are extremely high and unrealistic flow rates in the unit. This error was introduced in the beginning of 2011. For this reason these two telemetered data points are not valid for comparison purposes.

Figure 9 shows a trend of the telemetered and field collected data for KENOUNU01. This trend is limited to points collected before 1/1/2011 due to the modeling error for this unit.

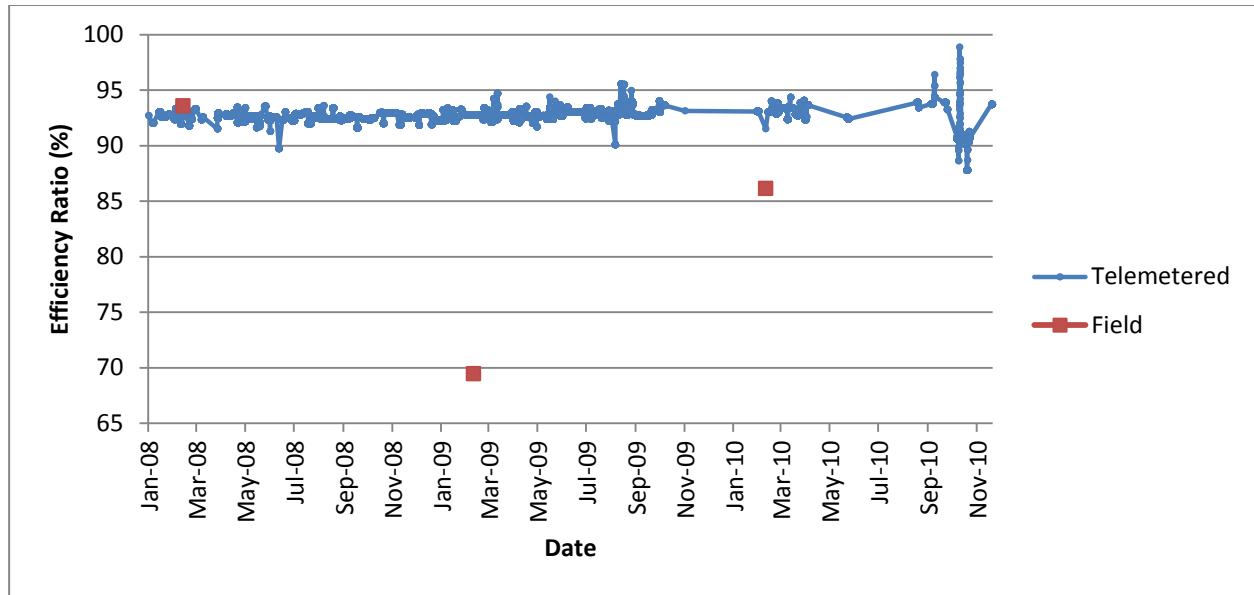


Figure 9. Trend of both telemetered and field efficiency data for KENOUNU01.

KENOUNU02. A single divergent point on 3/10/2010 coincides with one of the divergent points on KENOUNU01. Figure 10 shows this point to be low in comparison to other data collected on the unit.

It is interesting to note from figure 10 that tighter control of product properties for products units seems to translate to less variance in the telemetered efficiency ratio. This is as expected because there is less uncertainty in the properties of the fluid than crude oil batches.

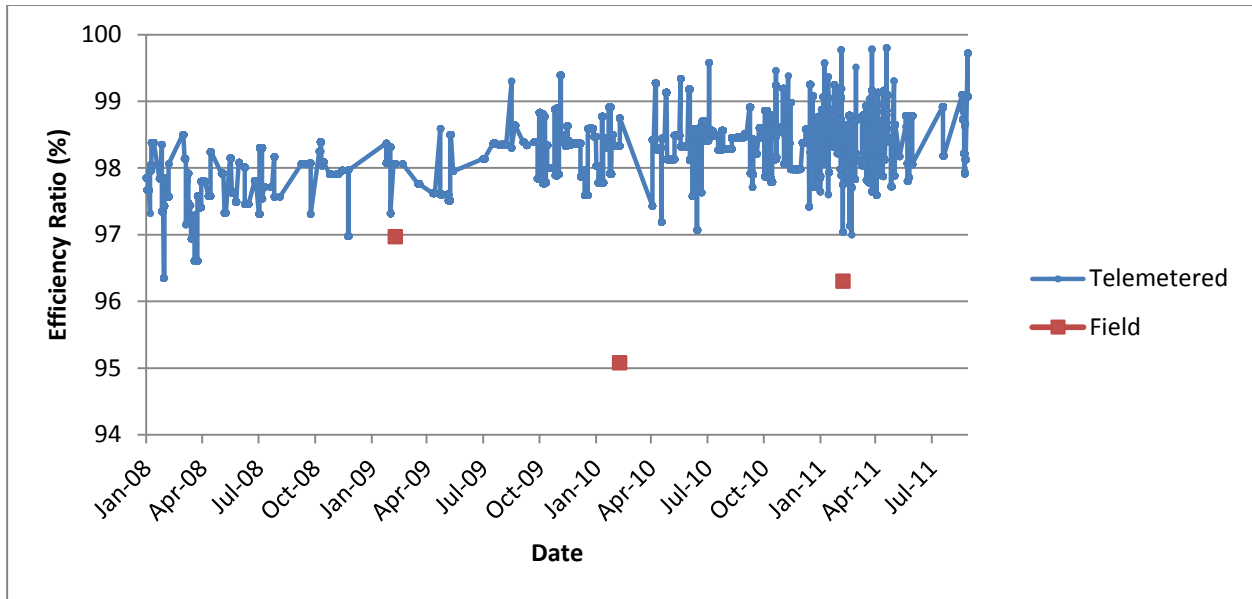


Figure 10. Trend of both telemetered and field efficiency data for KENOUNU02.

Additional Analysis

While the above analysis sufficiently supports the hypothesis, in the process of analyzing the data other interesting trends in the data were observed. This section discusses additional analysis that was performed and captures what was learned from the analysis.

The variation in efficiency ratio is much greater than expected. In order to investigate the source of this variation the data from DLGTUNU02 was used for analysis. This unit was chosen because of the wider product property variation of crude units. In addition this unit had more collected data points of the three crude units because of its high utilization. Examining figure 7 shows that over a short period of time this unit varied as much as 8-9 in the efficiency ratio.

Flow Rate. Some of this variation could easily be due to variation in flow rate. As shown in figure 2, unit efficiency is a strong function of flow rate. The choice of collecting

efficiency ratio (current efficiency/manufacture's efficiency) is intended to help negate this effect because the manufacturer's efficiency also changes with flow rate. This choice was validated by trending efficiency ratio over various subsets of flow and examining the efficiency ratio variation. An example of this is Figure 11 which trends efficiency ratio for flow rates between 8000 and 9000 BPH. In this range the manufacturer's efficiency curve is relatively flat, thus there should be little flow effect on efficiency ratio in this flow region. While this selection does reduce the variation magnitude to around 6-7 there is still significant variation.

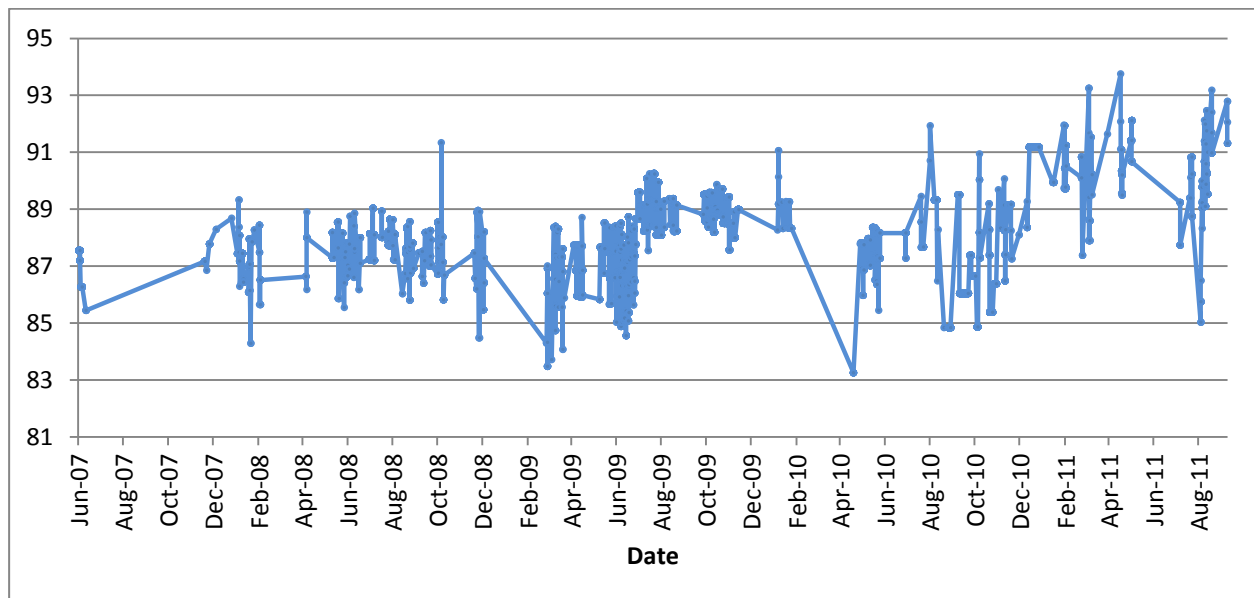


Figure 11. Trend telemetered efficiency ratio for DLGTUNU02, limited to flows between 8000 and 9000 BPH.

Viscosity. An obvious choice of the source of variation is the changing viscosity of batches pumped through the unit. This is one of the reasons why this property was collected along with flow rate and efficiency ratio. As shown in Figure 12 limiting the viscosity to a small number of values does not significantly reduce the variation of efficiency ratio.

The reduction in variation for both flow and viscosity could simply be because the number of batches trended is reduced. There are visibly fewer data points on both trends.

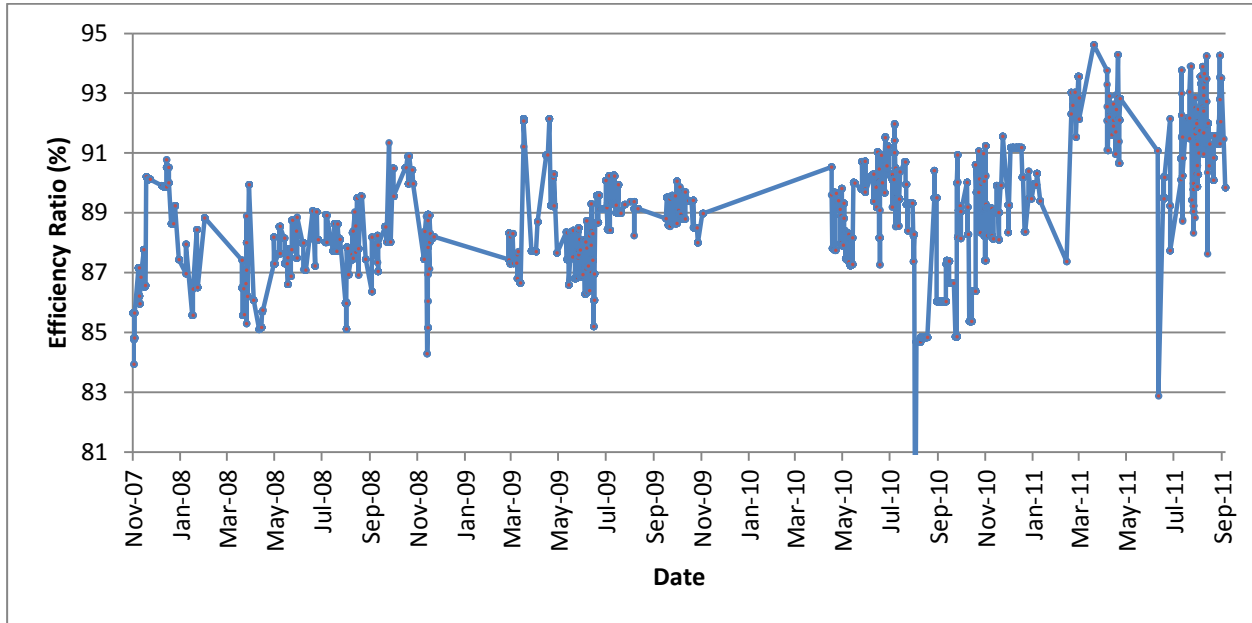


Figure 12. Trend telemetered efficiency ratio for DLGTUNU02 limited to viscosity less than 6 cst.

Time. Another collected variable that should account for variation in pump efficiency is time. Pump wear should drive a gradual decrease in pump efficiency over time, yet examination of Figure 9 shows an upward trend. Figure 13 shows the same data as Figure 9 with field data removed and a linear curve fit to the data inserted. In fact all the above unit efficiency ratios lack a continual downward trend.

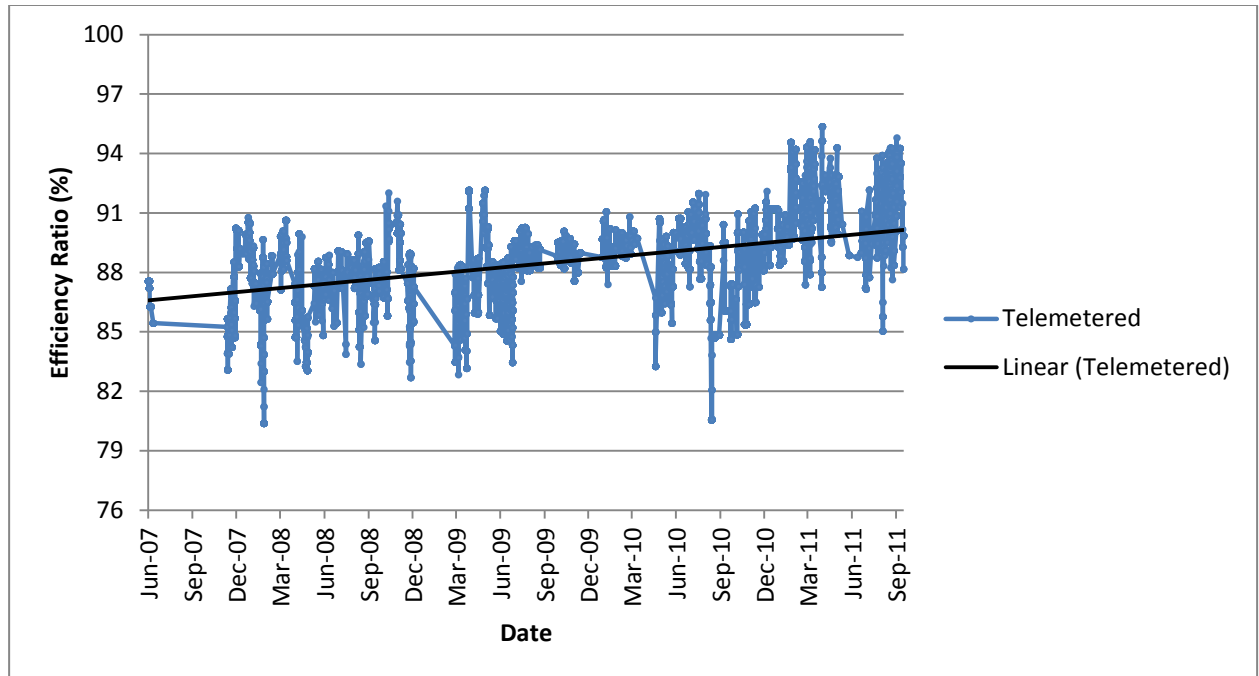


Figure 13. Trend of telemetered efficiency ratio for DLGTUNU02 with a linear curve fit.

CHAPTER 5

Summary, Conclusions and Implications

Overview

Chapter 4 presented the finding of the research and comparison of the telemetered data versus field collected data along with trends showing the results of the comparison. This chapter summarizes the problem, method and findings as well as provides a conclusion along with implications.

Summary of the Problem

Knowing the efficiency of a pumping unit has important operational and financial benefits to those who operate the unit. Historically efficiency is collected on a periodic basis through on-site collection of the necessary parameters. Unit efficiency can be calculated on a real time basis by combining telemetered data with fluid properties in a Real Time Transient Model (RTTM). This method however needs to be validated in order to ensure it is equivalent to field efficiency testing. The hypothesis for this research was that unit efficiency data calculated by combining telemetered data and modeled fluid properties are within one percent of the value collected using manual efficiency tests performed onsite.

Summary of the Method

The RTTM was expanded to be able to calculate unit efficiency utilizing telemetered data and modeled fluid properties. Three crude oil and two refined products units were configured in the model to perform the calculations. Data from each of the units was stored in a relational database for later analysis. Date and time, efficiency ratio (current efficiency/manufacturer's efficiency), flow rate and viscosity were stored once every fifteen minute. Field efficiency test data was retrieved and then compared to the telemetered data.

Summary of Findings

The results of the findings were previously presented in Table 1 for crude oil and Table 2 for refined products. Where the two methods did not correlate within the required one percent, the data was analyzed to determine the root cause. Three primary sources account for departures: (a) errors in the model's algorithm; (b) potential errors in field data collection; and (c) short runs of the unit just to collect efficiency. Once erroneous points are removed the remaining data points support the hypothesis.

Additional analysis was also performed to evaluate unexpected patterns observed in the data. No explanation could be found through evaluation of the collected variables. Since these unexpected patterns exist in both telemetered and field data, further research is needed.

Conclusions

Based on the above research findings, unit efficiency data calculated by combining telemetered data and modeled fluid properties are within one percent of the value collected using manual efficiency tests performed onsite. The additional data points collected through this method provides a more complete picture of the unit's efficiency. This evaluation supports using the RTTM to calculate efficiency in real time.

Implications

When the above research was performed, some improvement to the process was identified. This section attempts to document potential process improvement opportunities.

Having eliminated flow rate and viscosity variation as the source of efficiency ratio variation, the variation must be in some other variable that was not collected. Viscosity however is not completely eliminated because what was collected was modeled viscosity. The model does not have access to, or the ability to account for live viscosity measurements therefore this value is assigned based on historical samples of the fluid grade. The true viscosity of the current batch that is assigned to the grade could be very different from the modeled value. Density is another fluid property that is entered into the model and not telemetered. Either of these two parameters could account for the variations seen.

The wide variation of efficiency ratio, especially in crude units warrants further analysis to determine the root cause. The length of time over which the data was collected should also have shown degradation in efficiency. If this root cause can be found and accounted for a more realistic picture of efficiency should emerge. This could lead to pump efficiency degradation prediction.

The lack of time data in the field efficiency samples created unnecessary uncertainty in the evaluation process, requiring a judgment call when choosing the telemetered point for comparison. The field procedure should be changed to record the time of day that the field instruments were recorded.

The cause of telemetered efficiency spikes at pump startup should be investigated. If the root cause is found and eliminated then the data points at unit startup and shutdown would not need to be discarded.

The model has recently been expanded to collect field efficiency data for more units. The addition of power measurement to many sites has allowed this expansion. Additional analysis on this larger subset of the units would be beneficial, especially if time is recorded in the next round of field efficiency testing in the spring.

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