Heat Exchanger Monitoring—Predictive Analytics for Maintenance

Challenge

Heat exchangers play a crucial role in the downstream oil & gas industry. Prior to distillation, crude oil is heated through a series of exchangers called the preheat train. Additionally, heat exchangers are used to heat intermediate feeds prior to processing in various reactors.

As oil flows through the heat exchanger, deposits on the internal surfaces cause fouling, affecting the ability to transfer heat. In order to maintain the outlet temperature, the heat exchanger must be run at reduced capacity or, eventually, shut down and cleaned. Optimizing heat exchanger maintenance requires identifying when to modify operations to extend heat exchanger life vs. when to take the heat exchanger offline for cleaning.

A major U.S. oil & gas firm was operating its heat exchangers on a set maintenance schedule, taking them offline every few months for cleaning. But this resulted in inefficiency and incurred unnecessary cost.

The refinery was interested in enabling risk-based heat exchanger maintenance planning and optimization of processing rates, operating costs, and maintenance costs. Before using Seeq, the engineers had to manually combine data entries in a spreadsheet and spend hours if not days formatting and filtering the content and removing non-relevant data (for example, when equipment was out of service).

Solution

Using Seeq, the refinery's engineers were able to create a predictive model to anticipate when maintenance would next be required. The model also allowed them to investigate how changes in operating conditions could extend the time before maintenance. Additionally, Seeq made it easy to compare the current cycle with previous cycles to determine periods of accelerated fouling and diagnose the root causes.

The analysis was scaled out to monitor other heat exchangers at the refinery and other sites. Using Seeq to monitor heat exchanger performance in place of time-consuming spreadsheets eliminated weeks of work for engineers, freeing them up to perform other valuable tasks. The refinery expects to save millions of dollars per year as a result of improved turnaround planning and other improvement opportunities.

Results

The engineering solution drove long-term improvements for the refinery, including reduced production loss, at a savings of roughly $10,000 per year. In addition, migrating to risk-based maintenance planning reduced the impact on operations. Finally, this decreased the impact of unplanned rate reductions from heat-transfer constraints, enabling the refinery to avoid losing millions of dollars in opportunities from crude intermediate processing margins.

Data Sources

- Process Data Historian: OSIsoft PI, Gas Supply data from refinery, plant location temperature data, sea cooling water temperarture data.
- Heat Exchanger Design Data: Imported from the asset database or created in Seeq by engineer via scalars/signals.
- Thermodynamic data: Accessed via a lookup in Seeq or entered in Seeq by the engineer.

Data Cleansing

- Engineers can identify and remove irrelevant data from unit/equipment shutdowns as well as periods of abnormal operation to create a clean dataset for model generation.

Calculations and Conditions

- Capsules created with Seeq's Value Search and Custom Condition tools identify downtimes and abnormal operation
- Engineers apply "first principles" equations to calculate the Heat Transfer Coefficient (U) from temperatures and flow rates with Seeq's Formula tool.
- Seeq's Prediction tool is used to develop a model of the U-value as a function of time.

Reporting and Collaboration

- Seeq reports the date on which the prediction intersects with the minimum allowed U performance threshold to enable fast prediction of end-of-life cycle. Additionally, in monitoring mode, the prediction is updated as new data is acquired.
- Users can better avoid operational challenges by enabling maintenance and operations teams to make informed decisions about when remove the exchanger from service to avoid unplanned shutdowns.
- Seeq's Journal enables users to document detailed analysis steps for further review and process revisions.

HEAT EXCHANGER MONITORING & END-OF-CYCLE

CHALLENGE

- Proactively predict end-of-cycle for a heat exchanger due to fouling.
- Enable risk-based maintenance planning and optimization of processing rates (margin), operating costs (heat energy) and maintenance costs.

SOLUTION

- Using Seeq Formula, use first principles equations to calculate Heat Transfer Coefficient (U), from temperatures and flow rates.
- Use Seeq Prediction tool, create model to predict U-value data as a function of time.
- Determine date vs. known U performance threshold.
- Apply methodology to other heat exchangers.

BENEFITS

- Monitor heat exchanger performance degradation to allow risk-based maintenance planning.
- Optimize operational plans based on potential rate reduction penalties and planned maintenance costs.
- Minimize unplanned rate reductions from heat transfer constraint (when these exist), which can result in $millions of lost opportunity from crude/intermediate processing margins.
- Minimize unplanned maintenance requirements ($thousands).
- Payback by predicting and planning for one failure event.

STATISTICAL MODEL STEPS

1. PROCESS DATA
2. CALCULATION
3. PREDICTION

1.PROCESS DATA

Flow Rates	Cold Side Temperatures	Hot Side Temperatures
Hot Liquid Flow	Cold Liquid Inlet T	Hot liquid Inlet T
Cold Liquid Flow	Cold Liquid Outlet T	Hot liquid Outlet T

Total six process signals.

2.CALCULATION

2.1. Starting with input data

2.2. Calculate Hot, Cold and average duty MBTU's/Hour

Formula // $Q = m * c_p * dT$ //

($g * $j *($h * $i)).ConvertUnits(1 MMBTU/H)
Where
$h = Hot liquid Inlet T
$i = Hot liquid Outlet T
$j = Hot Liquid specific heat
$g =Hot liquid flow

2.3 Calculate hot approach & Cold approaches LMTD (Log Mean Temp Difference)

Formula

($e * $a) / (ln($e/$a))

Where
$e = Hot approach
$a = Cold approach

2.4 Calculate Heat Transfer (HT) coefficient

2.4.1 HT coefficient U- Value

Formula // Q = U * A * LMTD //

($Q / ($A * $LMTD) * 1000000 BTU / 1 MMBTU).remove($b)

Where
$b = bad data
$A = surface area
$Q = Average duty
$LMTD = Log Mean Temp Difference

2.4.2 HT coefficient U- Value(Normalized)

Formula

($i * $g / $k) * remove($a)

Where
$i = HT coefficient U- Value (BTU/(h * FA^2)
$a = bad data
$k = Hot Liquid flow (lb/h)
$g = Design Hot liquid flow

2.5 Apply scalars for design and minimum U – value

HT coefficient :U – value
HT coefficient :U – value normalized
Minimum U – value
Design U – value

Heat Transfer coefficient
Design criteria 100 BTU max & 30 BTU min

3.PREDICTION

3.1 Starting work step

3.1.1 create custom condition for current HX cycles

Current HX cycle work step
Click on edit custom condition
Select capsules from your capsules pane or input / select a new range

11/1/2016 7:00 AM – 1/30/2018 6:00 PM
Add
Start: 11/1/2015 1/1/2019 12:00 AM

3.1.2 create an accumulating count of days in service

Click on work steps with days in service

Formula // criteria time counter for the current cycle //

```
toservice(j).integral($a).convertunits(id)
```

3.1.3 create a prediction of HT coefficient qs a function of days in service

Click on edit predict HT coefficient U- value

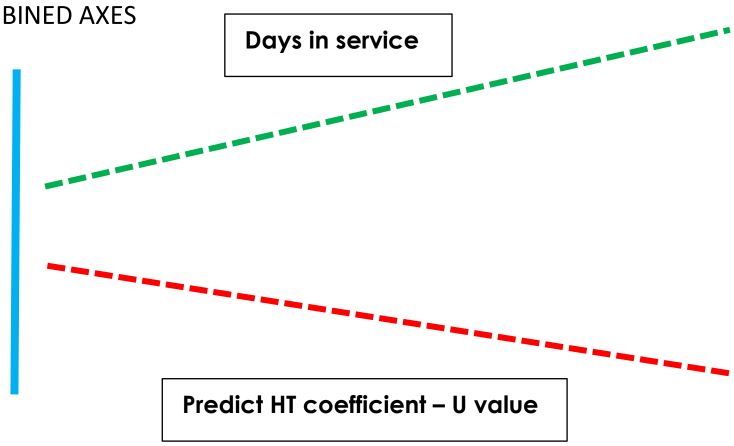
Signal to model → HT coefficient – U value (Normalized)
Input signals → days in service

Training window: 8/30/2015 12:57 PM - 10/9/2017 6:06 PM
Options: 1. Linear (selected option) 2. polynomial 3. Automatic

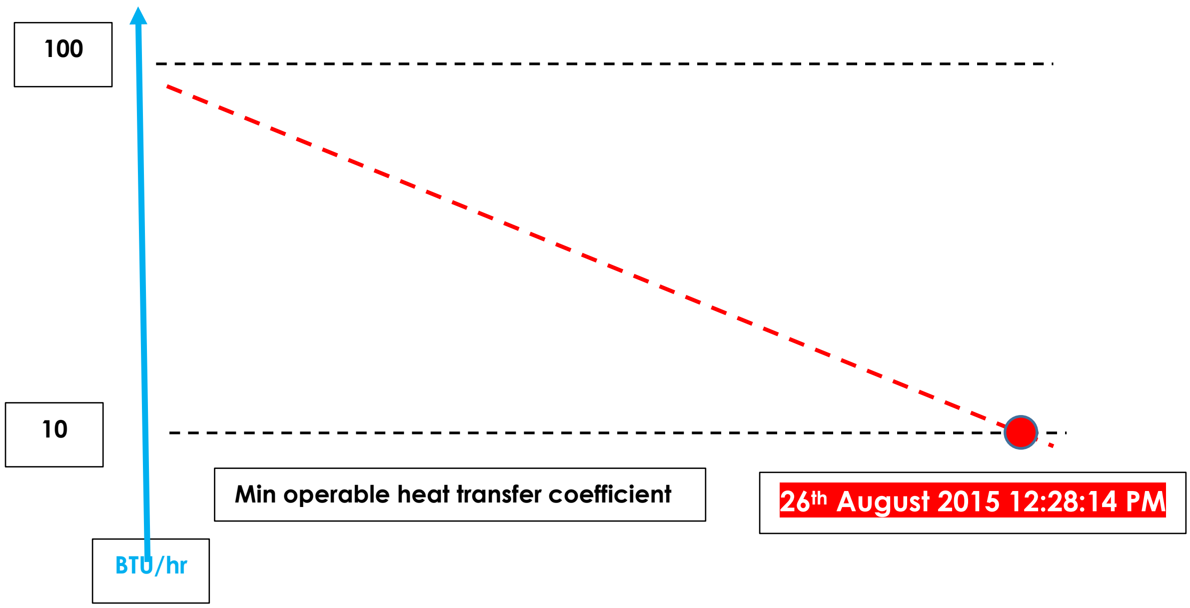
CLICK ON EXECUTE THE MODEL

3.1.4 GRAPHS

COMBINED AXES



COMBINED AXES

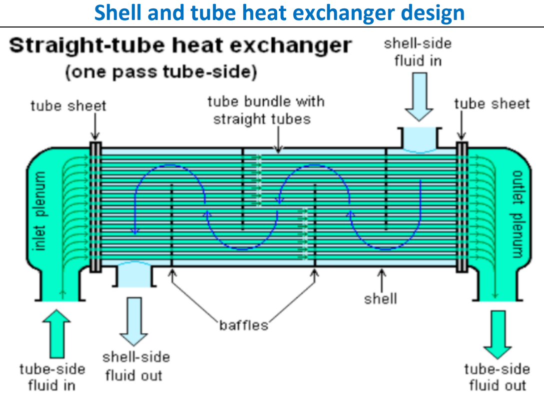
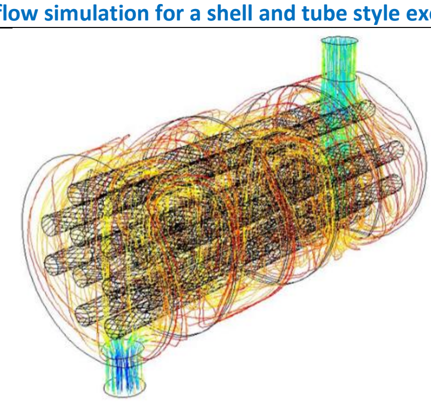


APPLICATIONS

1. Fouling & plugging
2. Rotating equipment
3. Determination of operational performance

HEAT EXCHANGER

Heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

Shell and tube heat exchanger design	Fluid flow simulation for a shell and tube style exchanger
	

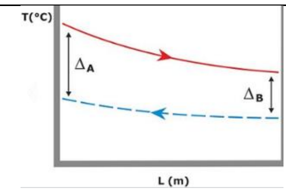
LOG MEAN TEMPERATURE DIFFERENCE (LMTD)

LMTD is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers.

he LMTD is a logarithmic average of the temperature difference between the hot and cold feeds at each end of the double pipe exchanger. For a given heat exchanger with constant area and heat transfer coefficient, the larger the LMTD, the more heat is transferred. The use of the LMTD arises straightforwardly from the analysis of a heat exchanger with constant flow rate and fluid thermal properties.

LMTD is defined by the logarithmic mean as follows:

$$LMTD = \frac{\Delta T_A - \Delta T_B}{\ln\left(\frac{\Delta T_A}{\Delta T_B}\right)} = \frac{\Delta T_A - \Delta T_B}{\ln \Delta T_A - \ln \Delta T_B}$$



where ΔTA is the temperature difference between the two streams at end A, and ΔTB is the temperature difference between the two streams at end B. With this definition, the LMTD can be used to find the exchanged heat in a heat exchanger:

Q = U * A * LMTD

Where **Q** is the exchanged heat duty (in watts), **U** is the heat transfer coefficient (in watts per kelvin per square meter) and **A** is the exchange area. Note that estimating the heat transfer coefficient may be quite complicated.

SELECTION OF TUBE MATERIAL

To be able to transfer heat well, the tube material should have good thermal conductivity. Because heat is transferred from a hot to a cold side through the tubes, there is a temperature difference through the width of the tubes. Because of the tendency of the tube material to thermally expand differently at various temperatures, thermal stresses occur during operation. This is in addition to any stress from high pressures from the fluids themselves.

The tube material also should be compatible with both the shell and tube side fluids for long periods under the operating conditions (temperatures, pressures, pH, etc.) to minimize deterioration such as corrosion.

All of these requirements call for careful selection of strong, thermally-conductive, corrosion-resistant, high quality tube materials, typically metals, including aluminium, copper alloy, stainless steel, carbon steel, non-ferrous copper alloy, Inconel, nickel, Hastelloy and titanium. Fluoropolymers such as Perfluoroalkoxy alkane (PFA) and Fluorinated ethylene propylene (FEP) are also used to produce the tubing material due to their high resistance to extreme temperatures. Poor choice of tube material could result in a leak through a tube between the shell and tube sides causing fluid cross-contamination and possibly loss of pressure.

FOULING

Fouling is the accumulation of unwanted material on solid surfaces to the detriment of function. The fouling materials can consist of either living organisms (biofouling) or a non-living substance (inorganic and/or organic). Fouling is usually distinguished from other surface-growth phenomena in that it occurs on a surface of a component, system, or plant performing a defined and useful function and that the fouling process impedes or interferes with this function.

Fouling of heat-transfer components through ingredients contained in cooling water or gases,