TOTAL
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REAL TIME CALCULATION AND CLOSED-LOOP CONTROL OF DEWPOINT AND SALT DEPOSITION TEMPERATURE AT A CDU, USING AN ONLINE ANALYZER

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AGENDA

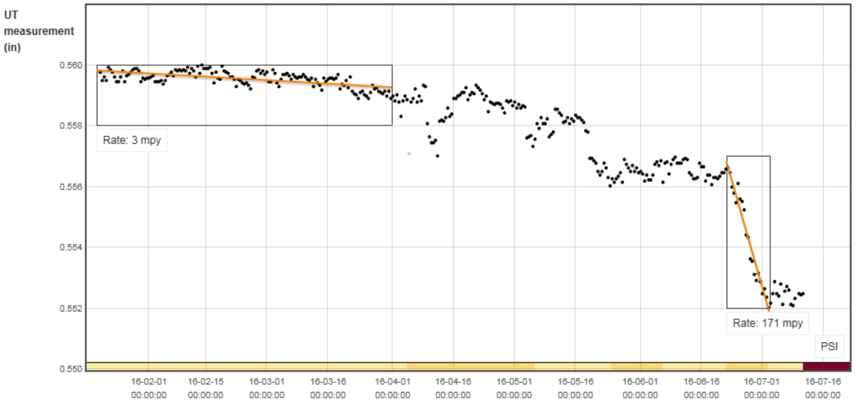
- Challenge
- Our solution
  - Analyzer
  - Offline/online Calculations
  - Closed-loop Control
- Conclusion

PROBLEM

- Inspection found that active corrosion is taking place at the CDU Naphtha pump-around circuit

CORROSION MECHANISM

- The corrosion mechanism involved here is “amine salts” (amines + HCl)
- Amines are very difficult to predict / monitor and have multiples sources (crude, slops, Sour Water Stripper)
- An amine oil/water separation will occur in the desalters depending on the pH of wash water and brine
- Formation of an acidic under-deposit corrosion (salts + corrosion products) on the exchanger bundles will continue till the deposits are washed away



Example of the corrosion probe monitoring showing accelerated pipe corrosion (decreased thickness)

TYPICAL WORK PROCESS

The Chemical Vendor, 3 times per week:

- Measures (among other things) Chloride and Ammonium concentrations in water – They may also measure Amines (MEA, DEA, …)
- Estimates dewpoint temperature and salt deposition temperatures (ammonium chloride & amine) using proprietary software
- Recommends the higher of the dewpoint and salt deposition temperatures, after adding a margin (NACE recommendation is 25 degF)
- Operations are then expected to respect that minimum recommended temperature by adjusting the overhead temperature of the CDU

Sour Water Analysis			
	V4	V5	
pH	6.1	6.8	
Chloride	17.4	0.6	ppm
Iron	0.00	0.00	ppm
Ammonia	65.0	23	ppm
Strong Acid	2.2	0.586	meq/L
Weak Acid	1.7	2.121	
Sulfide	15.0	50	ppm

	Calc'd Salt Points	
DewPoint	220.0	Deg F
DewPoint pH	2.5	
Neutralizer Demand	20.0	Gal/Day
NH4Cl Salt	236.0	Deg F
Amine Salt	167.0	Deg F
Salt Deposition Potential	0.0	Lb/Day
OH Temperature	265.0	Deg F
Total Recommended OH Temp.	271.0	Deg F

CHALLENGE

- What happens if the wash water composition, the process conditions or the crude composition change, in between lab analyses every couple of days?
- Is it feasible to calculate dewpoint and salt deposition temperatures in real time?
- TOTAL's corporate calculation standard explains that there are 2 methods for calculating dewpoint and salt deposition temperatures:
  - The simplified method
  - The 'iterative' method, which accounts for partial condensation of hydrocarbons, and therefore is more accurate
    - As one lowers the overhead temperature towards dewpoint, heavy hydrocarbons will condense
    - As less hydrocarbons are present in the vapor phase, the partial pressure of water will increase, so the dewpoint will increase

THE ONLINE ANALYZER

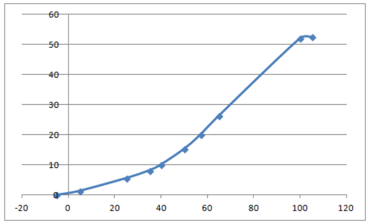
- 3D TRASAR™ Technology for Crude Overhead Systems (3DTCOS) is patented technology that measures pH, Cl, NH_3, and Fe
- Delivers near real-time overhead corrosion control, connected to the DCS (with alarming capability)
- The analyzer is often used to control neutralizer, filmer, and caustic injection
- The output is also used in some locations to adjust tower top temps to avoid potential ammonium chloride salting events and/or increase distillate/jet yields

3DTCOS – front (left) / back (right)

CALCULATIONS IN EXCEL

- Standard Inputs: Pressure and Flows
- Flow measurements can sometimes be an issue. The fix can be to build a correlation between valve output and flow
- Anything unmeasured ? Make a reasonable and conservative assumption
- Use consistent units (i.e. SI ☺)
- Document the conversion factors

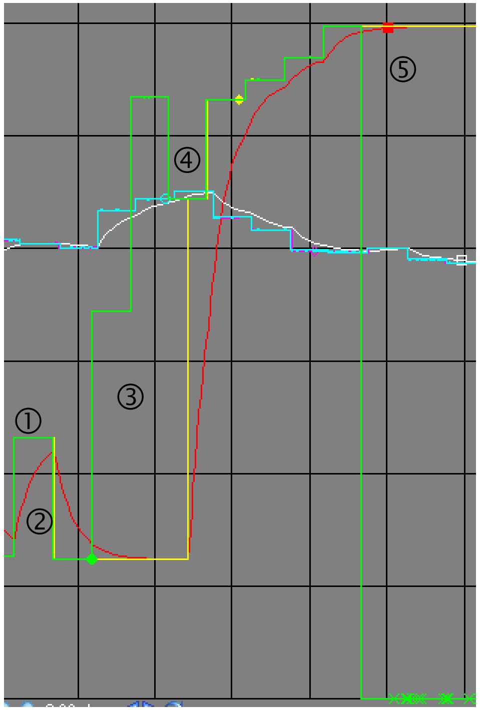
Overhead Pressure	BPR875	20.82	PSI	1.44	Bar
				2.44	Bara
Reflux	BFC837.OP	37.59	%		
Estimated Reflux		9.18	KBPD	60.84	M3/H
				44.41	T/H
Water flow	02FI871	59.68	GPM	13.55	T/H
	02FI870	17.24	GPM	3.91	T/H
Est. water in Reflux		2	%	0.89	T/H
Total water				18.36	T/H



1 LB	0.4535925	KG
1 B	158.9873	L
1 FT3	0.0283167	M3
1 G	3.7854099	L
1 SCF	0.002641	lbmol
API = (141.5 / SG) - 131.5		

ANALYZER VALIDATION

- Analyzers are special inputs
- Must be validated in real time, for:
  - Validity range
  - Freeze detection
  - Spikes
- Add filtering to avoid staircase effect



① Signal is valid – Raw and Validated measurements are superposed

② Filtered measurement lags the validated signal

③ Signal exceeds the rate of change limit, so Validated keeps the 'last good value'

④ But in fact the process has shifted, so the Raw and Validated measurements do superpose again

⑤ Analyzer fails and goes out of domain, so Validated keeps the 'last good value'

WATER BALANCE

- 2 Cases: 'Water OUT' or 'Water IN'
- Water OUT requires flow measurements for water out of the overhead drums
- Water IN uses instruments for stripping steam, typically underestimates water in crude, and relies on 3 analyses per week for % water in crude

Steam Flows	*BFFC832*	*1.44*	*MLB/H*	*0.65*	*T/H*	*Kero*
	BFC828	*2.00*	*MLB/H*	*0.91*	*T/H*	*FO*
	BFC829	*1.44*	*MLB/H*	*0.65*	*T/H*	*AGO*
	BFC822	*12.69*	*MLB/H*	*5.75*	*T/H*	*Bottom*
Total stripping steam				*7.97*	*T/H*	
Crude density online	*02DX2840.PV*	*21.21*	*API*	*0.93*	*T/M3*	
Crude density Lab	*B070T044.01*	*21.50*	*API*	*0.92*	*T/M4*	
Crude density	*02HS2822.PV*	*RUN*		*0.93*		
Crude Flow	*BFC800*	*149.31*	*KBPD*	*989.13*	*M3/H*	
				916.53	*T/H*	
Water content	*02-T035.VNDR1*	*0.60%*	*%VOL*			
Water in crude		*0.90*	*KBPD*	*5.50*	*T/H*	
Total water				*13.47*	*T/H*	

Water IN

Water flow	02FI871	59.68	GPM	13.55	T/H	V-4
	02FI870	17.24	GPM	3.91	T/H	V-5
Est. water in Reflux		2	%	0.89	T/H	Reflux
Total water				18.36	T/H	

Water OUT

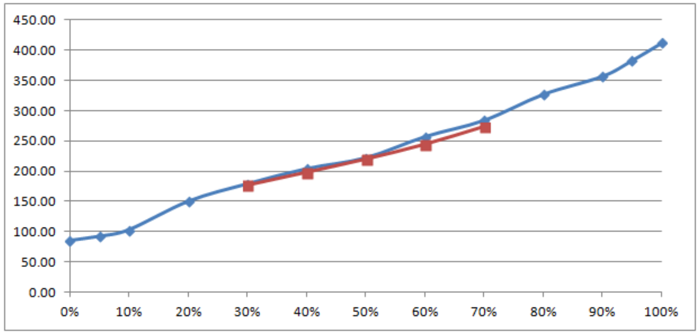
SIMPLIFIED METHOD

- Calculates partial pressure of NH_3 , HCl and H_2O, based on mass balance and total overhead pressure
- Calculates NH_4Cl salt deposition and dewpoint temperatures from Antoine equations
- Adds 35 degF to the higher of the 2 temperatures

PpNH3				5.69E-05	Bara	
PpHCL				1.42E-05	Bara	
Kp				8.09E-10		
T NH4CL		239.1	degF	115.0	degC	
PpH2O				0.88	Bara	
T H2O		204.9	degF	96.0	degC	
Recommended		**274.1**	degF			

ITERATIVE METHOD

- Uses Hot Drum Naphtha TBP curve (inferential, with bias update from the lab)
- Assumes a starting value for the dewpoint temperature
- Calculates the fraction of evaporated hydrocarbons if the overhead temperature were at dewpoint



02XI1T30I	30%	176.76	2	*198*	*40%*
	40%	197.97		*220*	*50%*
	50%	219.53		*a*	*0.0046*
	60%	243.89		*b*	*-0.5184*
02XI1T70I	70%	272.92		*% evap*	45.9%
				IBP	75

— Lab TBP

— Inferred TBP

ITERATIVE METHOD (CON'T)

- Calculates partial pressures from the new mass balance that accounts for condensed heavy hydrocarbons
- Calculates NH_4Cl salt deposition and dewpoint temperatures
- Loops until initial and final dewpoint temperatures are identical (DT=0)
- Adds 25 degF to the higher of the 2 temperatures

T guess		210.64	degF	99.24	degC
FHCVAP (hot drum)	at dewpoint			32.70	T/H
NBP	at dewpoint	142.82	degF	61.57	degC
MW	at dewpoint			82.44	
PpH2O	at %cond HC			0.99	Bara
T H2O		210.7	degF	99.3	degC
DT				0.0	degC
PpNH3				6.39E-05	Bara
PpHCL				1.60E-05	Bara
Kp				1.02E-09	
T NH4CL		242.1	degF	116.7	degC
Recommended		267.1	degF		

The iterative methods may lead to a higher estimated dewpoint, but TOTAL allows a reduced margin (25 vs. 35 degF) due to increased accuracy in the calculations

ONLINE CALCULATIONS

- In our case, online calculations are implemented using Aspen IQ, and are 'identical' to Excel
- All input variables are validated for BAD values, and critical variables are validated for range (e.g. water flows)
- But for each validation, we need to think about what we should do in case one input is found invalid. Because by default the rest of the calculations will become invalid as well

```
'OVHD Pressure (Bara)
P = PI875 * 0.0689475 + 1.0

'Water produced from V-4 and V-5 drums  (T/H)
WATDRUM = ( FI870V + FI871V ) * 60 * 3.78541 / 1000.

'Water in Reflux (T/H)
REF = FC837*158.9873/24*D_HD
WATREF = REF * H2O_REF/100

'Stripping Water (T/H)
STST = (FFC832+FC828+FC829+FC822) * 0.4535925

'Water in Crude (T/H)
If P208D = 1 Then API_CR = DX2840V
Else API_CR = API_LAB
Endif
D_CR = 141.5/(API_CR+131.5)
CRWAT = (FC800*D_CR)*158.9873/24.0*H2O_CRUDEV/100
```

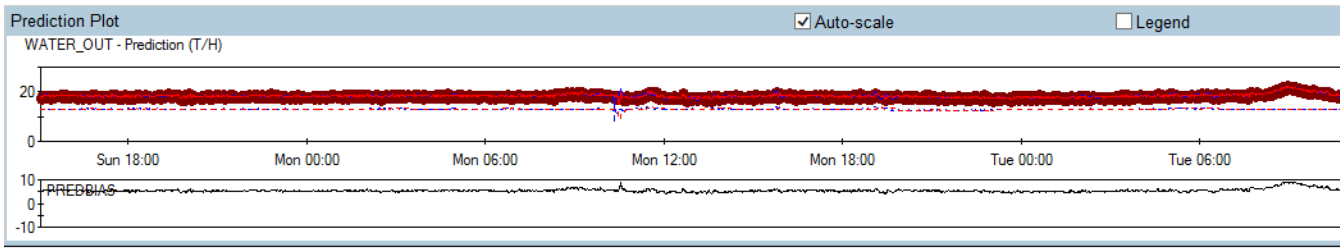
WATER IN VS WATER OUT

- Since we also calculate Water IN, we can use that value to infer Water OUT, and apply a bias calculated in real time
- So in case one of the water flows would be flagged invalid, we automatically use Water IN + bias instead

PREDICTION
Dynamic: 22.161
Steady State: 22.611
Bias: 3.729
Source: Analyzer Analyzer
Plot
Operate Tuning Model
Transform

ANALYZER
Value: 22.200
Time: 8/16/2016 3:02:45 PM
Bias: 3.729
Status: Good
Plot
Operate Tuning Validation
BiasCalc

INPUT CALCULATION
Operate



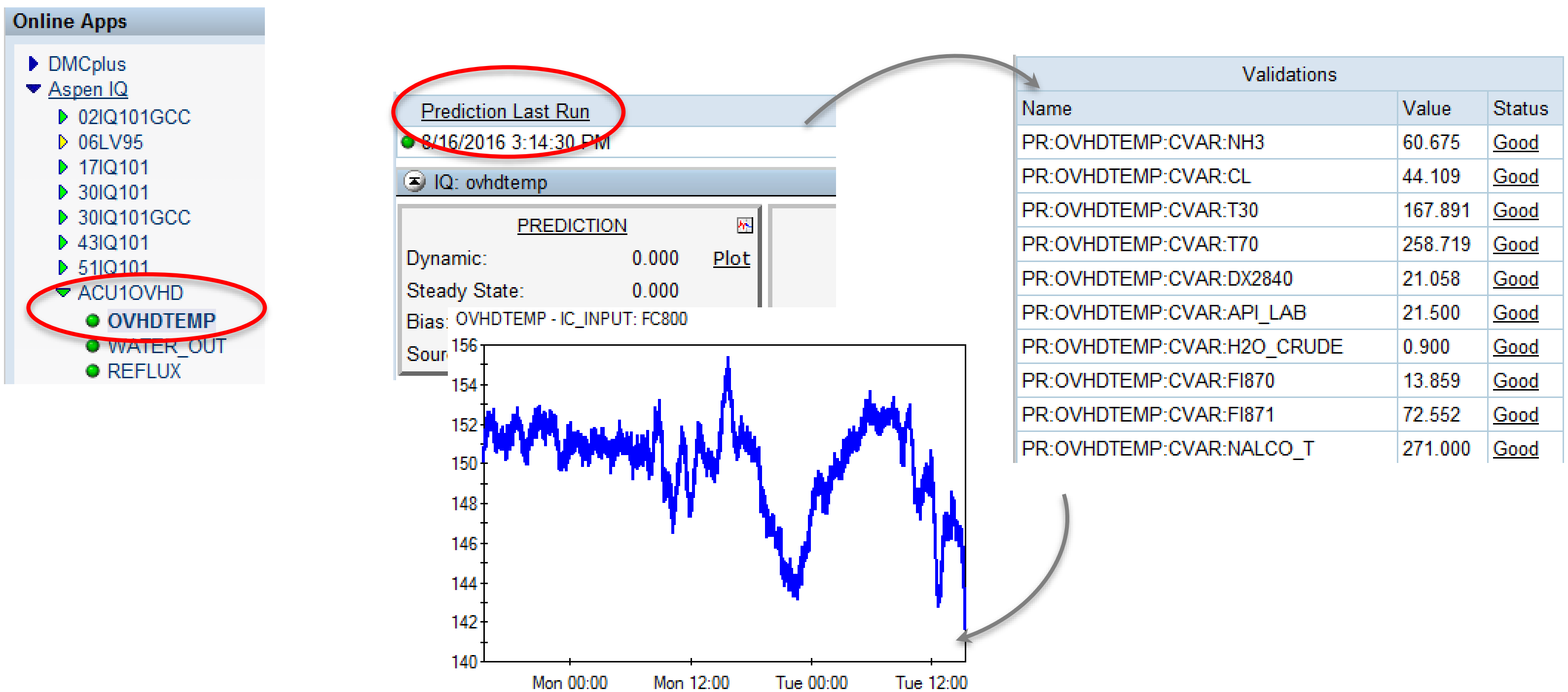
Detail Last 5 samples

Analyzer Previous Samples

Update Time	Raw Value	Unbiased Pred	Biased Pred	Avg Analyzer	Avg Unbiased Pred	Analyzer Bias	Cor
8/16/2016 3:02:45 PM	22.200	18.464	22.098	22.173	18.444	3.729	Good
8/16/2016 3:01:45 PM	22.253	18.434	21.987	22.055	18.420	3.635	Good
8/16/2016 3:00:45 PM	22.065	18.433	22.051	21.949	18.396	3.553	Good

INPUT VALIDATION AND TRENDS

- Both simplified and iterative methods are calculated online
- All inputs, validations, constants, intermediate calculations and final results are visible in the AspenTech Web Interface

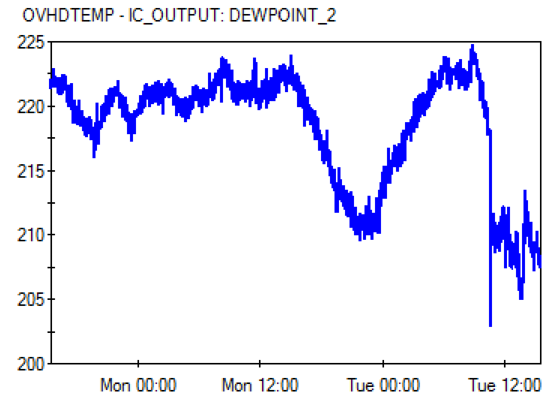


CALCULATION RESULTS

- Below are example of intermediate calculations and final results

Input Calculation Output Variables

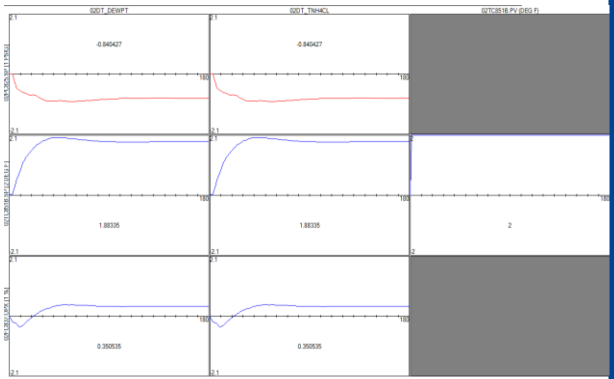
Label	Value	
ap	0.005	Good
API_CR	21.109	Good
bp	-0.521	Good
Count_Dewpoint_Old	0.000	Good
Count_TNH4CL_Old	0.000	Good
Crit_Dewpoint_Count	0.000	Good
Crit_TNH4CL_Count	0.000	Good
CRWAT	7.742	Good
D_CR	0.927	Good
DEWPOINT	203.663	Good
DEWPOINT_2	208.270	Good



- Results are written out to the DCS (once per minute)
- And made available in PHD and PI databases

ONLINE CONTROL

- In our case control is using Aspen DMCplus
- Inspection, Process Support, Operations and APC have agreed upon:
  - Controlling delta temperature from dewpoint and NH_4Cl deposition temperatures
  - Using the NALCO Champion minimum recommended temperature as a back-up in case the online analyzer would fail
- DMCplus models have been updated to include 3 new Controlled Variables, in the form of delta T from dewpoint, delta T from NH_4Cl, and NALCO Champion minimum temperature



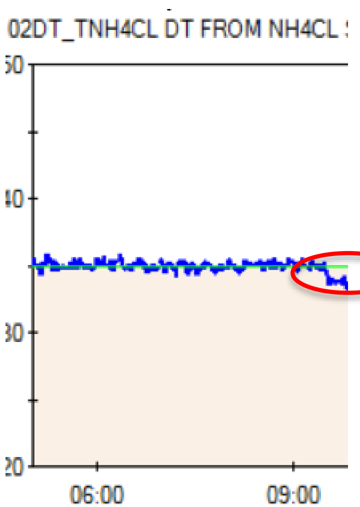
↗ Pressure ↘ ↘ DT's

↗ Temperature ↗ ↗ ↗ DT's

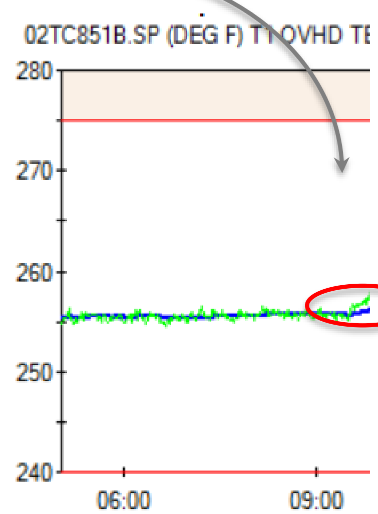
↗ Reflux ←→ DT's

TOTAL

CONTROL IN ACTION



Delta T is controlled at the limit, then it decreases slightly below the limit



As the delta T becomes lower than the limit, DMC increases the overhead temperature

FALL BACK MECHANISM

- What happens when the online analyzer fails or is flagged invalid, since we estimated that it is the highest risk of failure in the corrosion calculation sequence ?
  - We know that if the real-time validation of the online analyzer fails, the signal may become valid again a couple of hours later, depending on the type of validity check that didn't pass
  - So we start a counter immediately after the analyzer is found invalid
  - When the counter starts, DMCplus works using its internal predictions, without accounting for any new reading of the DT value from the DCS
  - If the counter reaches a maximum value of 4 hours, then the Controller Variable for DT NH_4CL turns OFF automatically
  - At the same time the minimum NALCO Champion recommended temperature Controller Variable turns ON automatically, and acts as a backup

CONCLUSION

- TOTAL Process Support, Inspection and APC have worked together to define the objectives and the constraints, and implement the calculations in Excel and online, with support from Operations, DCS and NALCO Champion
- Leveraging the use of an asset – the NALCO Champion online analyzer – as well as the strong incentive to minimize CDU overhead temperature – were the triggers for this project
- Making the closed-loop application robust, through the real-time validation of key inputs, is considered a best practice for APC
- Another analyzer for monitoring water in crude might be beneficial if ever the dewpoint constraint would become predominant
- At TOTAL PAR an acidification kit has been installed in 2017 to minimize amines in oil

BENEFITS

- Since the implementation of this application on 6/1/2016, the NH_4Cl salt deposition temperature has been in control for 93% of the time (control outages due to analyzer maintenance requirement and MVPC turned off at times)
- The main benefit of the approach is the control in real-time of the corrosion mechanism, and the expectation of an increased run-length of various process equipments
- Another significant benefit is the reduction of CDU overhead temperature (~ $ 2–9MM estimated benefits per year, as the combined result of acidification, online analyzers and real-time control)

QUESTIONS ?