The Use of Advanced Process Controls in a Phosphoric Acid Reactor

Vaughn Astley
The Use of ADVANCED PROCESS CONTROLS in a Phosphoric Acid Reactor

Vaughn Astley

Beneficiation of Phosphates VII
Melbourne, Australia

29th March to 3rd April, 2015
ADVANCED PROCESS CONTROLS (APC)

Remember, Remember when Automobiles/Cars has just a Steering Wheel, Gearlever, and Three Pedals???

Maybe a Direction Indicator Stalk, Maybe Windscreen Wipers Too!!

Independent Rear Suspension, WOW!!!

Now we have..............
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>4EAT</td>
<td>ABS</td>
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<td>AGVS</td>
<td>ARC</td>
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<td>AYC</td>
<td>CVRSS</td>
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<td>EBCM</td>
<td>EBD</td>
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<td>EDR</td>
<td>EGRCMDS</td>
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<td>LDAS</td>
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<td>NAICC</td>
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Who Knows What These Do?
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>4EAT</td>
<td>4 Speed Electronic Automatic Transmission</td>
</tr>
<tr>
<td>ABS</td>
<td>Antilock Brake System</td>
</tr>
<tr>
<td>ACE</td>
<td>Active Cornering Enhancement</td>
</tr>
<tr>
<td>ACC</td>
<td>Adaptive Cruise Control</td>
</tr>
<tr>
<td>ADAS</td>
<td>Advanced Driver Assistance System</td>
</tr>
<tr>
<td>AGVS</td>
<td>Automated Guided Vehicle System</td>
</tr>
<tr>
<td>ARC</td>
<td>Active Roll Control</td>
</tr>
<tr>
<td>ASR</td>
<td>Acceleration Slip Regulation</td>
</tr>
<tr>
<td>ASR</td>
<td>Automatic Stability and Traction Control</td>
</tr>
<tr>
<td>ASTC</td>
<td>Advanced Torque Transfer System</td>
</tr>
<tr>
<td>ATTS</td>
<td>Active Yaw Control</td>
</tr>
<tr>
<td>CVRSS</td>
<td>Continuous Variable Road Sensing Suspension</td>
</tr>
<tr>
<td>DMCM</td>
<td>Driver Motor Control Module</td>
</tr>
<tr>
<td>DSCC</td>
<td>Distance Sensing Cruise Control</td>
</tr>
<tr>
<td>EAS</td>
<td>Electrically Assisted Steering</td>
</tr>
<tr>
<td>EBCM</td>
<td>Electronic Brake Control Module</td>
</tr>
<tr>
<td>EBD</td>
<td>Electronic Brake force Distribution</td>
</tr>
<tr>
<td>EBTCM</td>
<td>Electronic Brake Traction Control Module</td>
</tr>
<tr>
<td>ECD</td>
<td>Electronically Controlled Deceleration</td>
</tr>
<tr>
<td>ECM</td>
<td>Engine Control Module</td>
</tr>
<tr>
<td>EDR</td>
<td>Event Data Recorder</td>
</tr>
<tr>
<td>EHCU</td>
<td>Electronic Hydraulic Control Unit</td>
</tr>
<tr>
<td>EHPAS</td>
<td>Electric Hydraulic Power Assisted Steering</td>
</tr>
<tr>
<td>EMAS</td>
<td>Engine Management and Analysis System</td>
</tr>
<tr>
<td>ETS</td>
<td>Enhanced Traction System</td>
</tr>
<tr>
<td>EVTOP</td>
<td>Enhanced Tactical Vehicle Occupant Protection</td>
</tr>
<tr>
<td>EGRCMDS</td>
<td>EGR Motor Commanded In Steps</td>
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<tr>
<td>FEDS</td>
<td>Flexible Engine Diagnostic System</td>
</tr>
<tr>
<td>HICAS</td>
<td>High Capacity Actively Controlled Steering</td>
</tr>
<tr>
<td>ICC</td>
<td>Intelligent Cruise Control</td>
</tr>
<tr>
<td>ICWS</td>
<td>Intersection Collision Warning System</td>
</tr>
<tr>
<td>IEDIS</td>
<td>Integrated Electronic Distributorless Ignition System</td>
</tr>
<tr>
<td>LDAS</td>
<td>Lane Departure Avoidance System</td>
</tr>
<tr>
<td>NAIICC</td>
<td>Navigation-Aided Intelligent Cruise Control</td>
</tr>
<tr>
<td>TCS</td>
<td>Traction Control System</td>
</tr>
<tr>
<td>VSES</td>
<td>Vehicle Stability Enhancement System</td>
</tr>
<tr>
<td>WVVWS</td>
<td>Wireless Vehicle to Vehicle Warning System</td>
</tr>
</tbody>
</table>
APC

WOW!!!
All These Computer Controls from the Cars Sensors!!
Improved Fuel Economy!
More Power From Smaller Engines!
Less Emissions!!
FASTER ACCELERATION!!!
More Stability  FASTER AROUND CORNERS!!!
Latest BMW has about 90 Computer Control Devices
Nearly All are Passive to Driver!!!!
APC

- Continuously Controls Sulphate, $P_2O_5$ Strength and Operating Rate of PhosAcid Plants.....
  - PhosAcid Cruise Control!!!!!!

- Development History
- How it Works
- How it Performs
- Benefits
- How it is Installed
History of Original Development and Implementation

- 1980’s, IMC & Agrico Advisory Programs for Sulphate Control
- Took ~2 Years to get the Sulphate Control to Perform,
- Took ~4 years to get the $P_2O_5$ Gravity and Filter Feed Controls to an Acceptable Operational Status.
- On-Line Control System for Sulphate, Rate and Strength Control Implemented by IMC in 1991 at Three New Wales Plants
  - Installed at South Pierce, Faustina, and Uncle Sam after Merger with Agrico in 1993
  - Partial Installation at Riverview and Bartow After Merger with Cargill to Form Mosaic in 2004
Current Development and Implementation

- Improved Program and Logic Codes Written From Scratch and Operator/Supervisor/DCS Interaction Improved in 2006
- Wash Water Pulse Eliminated

Many Inquiries, but Installed at Only One Other Plant.
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SO HOW DOES IT WORK!!!!
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- Sulphate Control
- Phosphoric Acid Strength Control
- Filter Feed Control
- Filter Feed Level Control
- By ............Finally Controlling Rock Rate
PHOSPHORIC ACID FLOWSHEET

- Attack
- Filter Feed
- Filtrate Acid
- Recycle Acid
- Calcium Sulphate
- Sulphuric Acid
- Bypass Water
- Rock
- Sluice Water?
- Filter Wash Water

APC
Sulphate Control

- Measure Sulphate in PhosAcid each Hour (Flexible)
- Targeted Sulphate Level is Set (performance)
- Acid to Rock Ratio Adjusted to Attain Target
- Ratio Adjusted After Sulphate Sample Result Entered
- Corrects Each Time Based Upon How Previous Adjustments Performed!!!!
Target: ???
Act Avg: 2.20
Std Dev: 0.36

BC (Before Computers)
SO₄ Control

Wt % SO₄

March, 1988
On-Line
SO$_4$ Control

Target  2.00
Act Avg  2.00
Std Dev  0.12

November, 1990
SO₄ Standard Deviation

More recent 2007 - 2010 Data

Average Free Sulfate Difference from Target

<table>
<thead>
<tr>
<th>Date Range</th>
<th>Average Free Sulfate Difference from Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 21, 2004-Sept 30, 2007</td>
<td>0.400</td>
</tr>
<tr>
<td>August 26, 2009-Jan 20, 2010 As Is With Control Program</td>
<td>0.146</td>
</tr>
<tr>
<td>August 26, 2009-Jan 20, 2010 With Latest Adjustments</td>
<td>0.139</td>
</tr>
<tr>
<td>Feb 1, 2010-March 23, 2010 With Latest Adjustments</td>
<td>0.119</td>
</tr>
</tbody>
</table>
Sulphate Control..............................................Done

Next We add:-

Phosphoric Acid Strength Control
  – P2O5 target…Based on Downstream Needs
  – Continuously Monitors Water to Rock Ratio
  – Adjusts Filter Wash Water
  – Controls By-Pass Water
  – Adjust Ratio After Every Sample, (Hourly)
  – Corrects Each Time Based Upon How Last Adjustments Performed!!!!
PHOSPHORIC ACID FLOWSHEET

- Attack
- Sulphuric Acid
- Bypass Water
- Rock
- Filter Feed
- Filtrate Acid
- Calcium Sulphate
- Filter
- Recycle Acid
- Sluice Water?
- Filter Wash Water
Target: 28.20
Actual: 28.13
Std Dev: 0.53

BC (Before Computers)

$P_2O_5$ Control

Wt % $P_2O_5$

January, 1990
BC (Before Computers)
P$_2$O$_5$ Control

31 Days of January, 1990

Target  28.20
Actual  28.13
Std Dev  0.53
Target    28.38
Actual    28.38
Std Dev   0.32

Wt %  P$_2$O$_5$

On-Line  P$_2$O$_5$ Control

January, 1993
On-Line
P2O5 Control

30 Days of November, 1993

Target    28.38
Actual    28.38
Std Dev   0.32
Was       0.53
APC

- Sulphate Control ........................................Done
- Phosphoric Acid Strength Control.........Done
- Next We Add:-
- Filter Feed Control
  - Tail Wash Filtrate Density Needed
PHOSPHORIC ACID FLOWSHEET

- Sulphuric Acid
- Bypass Water
- Rock
- Attack
- Filter Feed
- Filtrate Acid
- Recycling Acid
- Sluice Water
- Filter Wash Water
- Calcium Sulphate
- Density
PHOSPHORIC ACID PLANT ON-LINE CONTROLS

- Sulphate Control ..................................... .....Done
- Phosphoric Acid Strength Control...........Done
- Filter Feed Control
  - No. 3 Filtrate Density Target
  - Density Target Sets Filtration Recovery
  - Filter Feed Rate Set is Based on Final Filtrate Density
One Attack..... Three Filters!!!!!
Sulphate Control ........................................Done

Phosphoric Acid Strength Control..........Done

Filter Feed Control

Finally We Add:-

Rock Rate

- Rock Rate Set is Simply Based on the Filter Feed Level
PHOSPHORIC ACID FLOWSHEET

- Attack
- Level
- Filter
- Recycle
- Filtrate
- Acid
- Rock
- Sulphuric Acid
- Bypass Water
- Filter Wash Water
- Sluice Water
- Calcium Sulphate
Initially Sulphate Control was the Focus for First Two or Three Years.

The Next Several years were Needed to Optimize the Programs Used to Control the More Complex P₂O₅ Attack Gravity.

Finally, Again Three or so Years Needed for the Slurry Filter Feed and Filter Operation to be Perfected.

So What Happened??
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How it Performed
P2O5 Recovery vs Time

Add Automatic Controls
P2O5 Recovery vs Time

Monthly

5 Month Rolling Avg

- Add Automatic Controls
P2O5 Recovery vs Time

-4.00
-2.00
0.00
2.00
4.00
6.00
8.00

JAN, 84
JAN, 85
JAN, 86
JAN, 87
JAN, 88
JAN, 89
JAN, 90
JAN, 91
JAN, 92
JAN, 93
JAN, 94

%P2O5 Recovery Change

Monthly 5 Month Rolling Avg

Add Automatic Controls

Add More Controls
Average Daily Production

- Monthly
- 5 Month Rolling Average

% Production Change

Make Changes
Did the On Line Controls Give an Improvement of about 0.5% or 7%?

It Did Both

The Reduction in Water Soluble/Citrate Soluble Losses in the Gypsum was About 0.75%

However, Other Losses Also Decreased
  - Flash Cooler Losses
  - Less Upsets on Filter and Filterability
  - Line Scrub Losses (Less Build Up, Steadier Super-Saturation levels)
  - Less Filter Scaling (Ditto)
  - Tank Clean Out Losses
  - Less Frequent Down Days

A Smoother Operation Leads to Many Improvements Downstream
In Early On Line Control System Implementations

- The Reduction in Filter Losses After the Implementation of On-Line Controls was About 0.5 - 1%

- (But at a Higher Rate and With an Inferior Rock Quality)

- But the Improvement in the Overall Recovery for the PhosAcid Facility was Over 7%

Results Will Depend on How Well Current Facility is Operated!!!
● How It All Links Together…..
The PhosAcid Control Strategies

Filter Feed
- No. 3 Filtrate Density Target
- Filter Feed
  - Filter Wash Water
  - Bypass Water

Sulphate
- Sulphate Target
- $\text{H}_2\text{SO}_4$
- Rock
  - $\text{P}_2\text{O}_5$ Strength
    - $\text{P}_2\text{O}_5$ Target

Rock Rate
- Filter Feed Level
The PhosAcid Control Strategies

- **No. 3 Filtrate Density Target**
- **Sulphate Target**
- **Filter Feed**
- **Sulphate**
- **H₂SO₄**
- **Rock**
- **P₂O₅ Strength**
- **P₂O₅ Target**
- **Filter Wash Water**
- **Bypass Water**
- **Filter Feed Level**
- **Rock Rate**
- **Rock Rate**
The PhosAcid Control Strategies

- Filter Feed
  - No. 3 Filtrate Density Target
  - Filter Feed

- Sulphate
  - Sulphate Target
  - $\text{H}_2\text{SO}_4$
  - Rock
  - Filter Wash Water
  - Bypass Water

- Rock Rate
  - Filter Feed Level

- $\text{P}_2\text{O}_5$ Strength
  - $\text{P}_2\text{O}_5$ Target
The PhosAcid Control Strategies

Filter Feed
- No. 3 Filtrate Density Target
- Filter Feed

Sulphate
- Sulphate Target
- H₂SO₄
- Rock
- Filter Wash Water
- Bypass Water

Rock Rate
- Filter Feed Level

P₂O₅ Strength
- P₂O₅ Target
PHOSPHORIC ACID PLANT ON-LINE CONTROLS

- Control Limits and Logic (Some Fuzzy) for
  - Multiple Filters and Flow Partitioning
  - Upset Conditions
  - Data Entry Errors
  - Rate and Flow Limits
  - Adaptive In That Drift In Instrumentation Has Little Effect
  - Use of Data to Enhance Operations
Large Rate Improvements

- Increased Reactor/Filter Rates
  - Higher Average Operating Rates

- Increased Operating Time Due to:
  - Less Frequent Filter Scrubs
  - Longer Times Between Turn-Rounds
  - Less Line Scaling
How Are Other Attacks Controlled Now?

- Characteristics of Currently Operating Control Systems
  - Use Look-Up Charts…
  - Bump and Step Charts,
  - Tables of Adjustments
  - Simple Programs.. Enter SO$_4$ Deviation and Rock Rate, Tells Operator How to Change Sulphuric Acid.
  - What-If diagrams.
  - Need Constant Attention of Operator
  - Wouldn’t Cruise Control be Better?
  - i.e. Even Stability Control!!
APC

How it is Installed
SO HOW TO CATCH UP!!

What we do............

- Two Week Site Visit, Evaluation of Plant Performance, Lab Data, and Analysis of Electronic DCS Data,
- Need 3 to 6 months of 1 Minute DCS and All Laboratory Loss Data, (250,000 rows!!!)
- We Estimate Benefit to Recovery and Production,
- We Determine Cost of Full APC Installation, Including Training,
- About $34K (Intn’l) to Accomplish This First Step

- THEN, if Acceptable, Implement Full APC
Is Control too Complicated and Costly to Install and Maintain?

- (Turn-Key… ~$400,000 to Install for Domestic, ~$500,000 for International Facilities and <$5,000/Yr to Maintain)
- Similar Trains are ~$100K Each

Do We Need On-Line Analysis

- You Don’t need Continuous Analysis, Just The Routine Hourly Sulphate and Gravities is All that is Needed!!!
Implementation Of Full APC

- Site Visits to Observe Operations and Collect Data.
- A Year or Two of Electronic (1 Min DCS Data), & Lab Data to Develop Computer Control Programs
- DCS Programming with Operational Code
- Operator Training and Debugging
- Several Site Visits for Installation and Training
- Stepwise Commissioning, and Operator Training in:
  - Free SO$_4$ Operation & Control,
  - Target P$_2$O$_5$ Strength Control,
  - Filter Feed and Multi-Filter Operation,
  - Finally Level Control & Rock Feed.
Implementation Of Full APC

Total Installation Cost Say About $450K

A 1% Recovery Improvement at 4000 tpd $P_2O_5$ is 40 tpd
A 2% Production Improvement at 4000 tpd $P_2O_5$ is 80 tpd

At Roughly $350/ ton $P_2O_5$ @ 120tpd is thus $40,000 per day!!

• About a 12 Day payback!!

If you are @ 1200 tpd $P_2O_5$ then about a Month!!!
SMOOOOOOOTH Running!!

Poor Operation, $980,000 pa.
Higher Losses $750,000 pa.
Upsets, Plant Crashes, $850,000 pa.
Higher Scaling Costs, $350,000 pa
Operator Mistakes $699,997.7 pa.

Good Control….Priceless (MasterCard Ad)

Thank You

VaughnAstley@DrPhosphate.com

A Set of Notes in French are shown in “notes’ view
Des commentaires en langue Française de la présente présentation y sont incluses