Flare Control System Design
For Refinery Flares to Comply with RSR 63.670 Rules

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EPA Targeted Illegal Air Emissions

From www.EPA.gov
Key Limits and Monitoring

EPA and RSR Regulations

- Vent Gas NHVvg $\geq 300$ Btu/scf. (This is in Subpart A)
- Combustion Zone NHVcz $\geq 270$ Btu/scf.
- Combustion Efficiency (CE) $> 96.5\%$.
- Net Heating Value Dilution Parameter (NHVdil) $> 22$ Btu/sq. ft).

Real-Time Monitoring System

- The new RSR 63.670 rule is based on a quadratic 15-min data block. (Minute 0 to 15, 15 to 30, 30 to 45, and 45 to 60). If flare starts at minute 12, that data point collected is still counted for the first 15-min block.
- An online calorimeter such as Hobre and/or Extrel is needed to measure the vent gas heating value, NHVvg.
- Proper gas and steam flow sensors are needed to calculate and store NHVcz and NHVdil as part of the monitoring system.
Combustion Zone Heating Values

For Steam Assisted Flares

\[ NHV_{cz} = \frac{Q_{vg} \times NHV_{vg}}{Q_{vg} + Q_{s}} \] (Btu/scf)

NHV\textsubscript{cz} – NHV of Combustion Zone, \( NHV_{vg} \) – NHV of Vent Gas.

\( Q_{vg} \) – Volumetric Flow of Vent Gas, \( Q_{s} \) – Volumetric Flow of Steam.

For Perimeter Assisted Flares

\[ NHV_{cz} = \frac{Q_{vg} \times NHV_{vg}}{Q_{vg} + Q_{a}} \] (Btu/scf)

\( Q_{a} \) – Volumetric Flow of Premix Air.
Net Heating Value Dilution Parameter

For Perimeter Assisted Flares Only

\[ NHV_{dil} = \frac{Q_{vg} \times Diam \times NHV_{vg}}{Q_{vg} + Q_a + Q_{a2}} \quad (Btu/ft^2) \]

Diam – Diameter of flare tip for flare vent gas flow,

NHV_{vg} – NHV of Vent Gas,

Q_{vg} – Volumetric Flow of Vent Gas,

Q_{a} – Volumetric Flow of Premix Air,

Q_{a2} – Volumetric Flow of Perimeter Air.

EPA does not tell you how to comply. For control, we need to use real-time data and trends. 15-min block data is not sufficient.
Flare NHVcz and NHVdil Control

Why Are NHVcz and NHVdil Control Difficult

- The vent gas flow can change widely and quickly,
- The heating value in vent gas can change widely and quickly,
- The assist air and/or steam needs to have a proper ratio to the total amount of vent gas and its contained heating value, where NHVcz and NHVdil are good indicators,
- Nitrogen is often used as purge gas to maintain positive pressure in the vent pipe, making the process more complex,
- There are large and varying time delays in the heating value control loops, especially for the NHVcz loop, and
- The heating value process is extremely nonlinear in different operating conditions.

PID-based or model-based closed-loop heating value control system are difficult to design, commission, and maintain.
MFA Flare Heating Value Control

Model-Free Adaptive (MFA) Flare Control System Diagram

- AI-01 Vent Gas Heating Value
- FI-02 Vent Gas Flow
- FI-03 Assist Steam Flow

Supplemental Gas (Natural Gas)

Purge Gas (Nitrogen)

Waste Gas from Multiple Streams

MFA Heating Value Control System

Steam to Vent Gas Ratio Control

Waste Gas Flow Signals

SP=350

Volatile Gas Heating Value

Assist Steam Jets

Ignition Gas

Pilot Gas
MFA Control of Vent Gas Heating Value

Heating Value SP = 350 Btu/scf - Blue

Heating Value PV (Btu/scf) - Green

Controller OP (0-100%) - Red

EPA Limit = 300 Btu/scf - Yellow

Vent Gas Flow - Grey
MFA vs PID Heating Value Control
Control for Steam Assisted Flares

Control of Vent Gas Heating Value, \( NHV_{vg} \)

- It is important to automatically control \( NHV_{vg} \) so that it is above 300 Btu/scf. If \( NHV_{vg} \) is not under control, \( NHV_{cz} \) will have no chance to comply with the 270 But/scf limit.

Control of Steam Flow, \( Q_s \)

- \( NHV_{cz} \) is proportional to \( NHV_{vg} \) relating to the volumetric steam flow \( Q_s \). To assure \( NHV_{cz} > 270 \) But/scf., \( Q_s \) must be effectively controlled. (See Formula (1) on Page 7)
- Too low of \( Q_s \) will result in a smoking flare which is prohibited.
- Too high of \( Q_s \) will cause \( NHV_{cz} < 270 \) But/scf.

Control of Combustion Zone Heating Value, \( NHV_{cz} \)

- The MFA Combustion Zone Heating Value Control System uses an Anti-delay MFA controller to deal with large and varying time delays.
MFA NHVcz & NHVvg Cascade Control
Online Btu Sensor & Poor Steam Control
Slow GC Data & Good Steam Control
Slow GC Data & Poor Steam Control
MFA Control for Air Assisted Flares

- AI-01: Vent Gas HV
- AI-02: Combustion Zone HV
- AI-03: Net HV Dilution Par
- FI-01: Supplement Gas Flow
- FI-02: Vent Gas Flow
- FI-03: Air / Steam Flow

Combustion Zone Heating Value Control

- HVcz OP to HVvg SP
- HVcz SP

Net Heating Value Dilution Control

- NHVdil SP

Stoichiometric Ratio Control

- Combustion Efficiency Constraint

Supplemental Gas (Natural Gas)

- Purge Gas (Nitrogen)

Waste Gas Flow Signals

- Cascade from HVcz Control
  - SP Low Limit = 350 Btu/scf

MFA Vent Gas HV Control System

- Assist Air
- Air Flow
- Vent Gas Flow
- Ignition Gas

Waste Gas from Multiple Streams
Model-Free Adaptive (MFA) Control

Control Objective

- Controller to produce OP to force PV to track SP or minimize e(t).

MFA controls complex systems

- No process models;
- No identification;
- No controller design;
- No manual tuning.

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Inside MFA

No Model
- A neural network is part of the MFA controller.

Adaptive
- Weights are updated to help minimize $e(t)$.

Robust
- Provides much wider robust range than PID.

Speed
- Controls immediately, no waiting on model building.
Running CyboCon Demo
## MFA Advantage & Suitability

<table>
<thead>
<tr>
<th>Item</th>
<th>PID</th>
<th>MBC</th>
<th>MFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>General purpose</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Adaptive</td>
<td>N</td>
<td>Y/N</td>
<td>Y</td>
</tr>
<tr>
<td>No process model</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>No identification</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>No controller design</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>No manual tuning</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Controls complex systems</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Easy to use and maintain</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
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### Application Suitability

- **PID**: one algorithm for all, **MBC**: one algorithm fits one system, **MFA**: one algorithm solves one control problem.

**MFA** is suitable for Grey box problems, where the process has uncertainties including load, fuel, and dynamic changes, etc.

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# MFA Controllers at a Glance

<table>
<thead>
<tr>
<th>Controller Name</th>
<th>Control Problems Solved</th>
</tr>
</thead>
<tbody>
<tr>
<td>SISO MFA</td>
<td>Controls a wide variety of processes</td>
</tr>
<tr>
<td>MFA (Turbo)</td>
<td>Adapts, no manual tuning required.</td>
</tr>
<tr>
<td>MIMO MFA</td>
<td>Controls multivariable processes</td>
</tr>
<tr>
<td>Nonlinear MFA</td>
<td>Controls extremely nonlinear processes</td>
</tr>
<tr>
<td>MFA pH</td>
<td>Controls pH processes</td>
</tr>
<tr>
<td>Anti-delay MFA</td>
<td>Controls processes with large time delays</td>
</tr>
<tr>
<td>Anti-delay MFA pH</td>
<td>Controls pH processes with large time delays</td>
</tr>
<tr>
<td>MFA Flare Heating</td>
<td>Specially designed to deal with nonlinear, varying time delays, and large disturbances.</td>
</tr>
<tr>
<td>Value Control Solution</td>
<td></td>
</tr>
<tr>
<td>Feedforward MFA</td>
<td>Deals with measurable disturbances</td>
</tr>
<tr>
<td>Robust MFA</td>
<td>Forces PV to stay within its bounds</td>
</tr>
</tbody>
</table>
The Switch block in PLC is to switch between MFA and PID.

An MFA Button is added to the HMI screen so that the operator can easily switch the system between MFA, PID, or manual control.
Recognized as Industry Leader

Prestigious awards validate the impact of MFA to the industry.

CyboCon CE with a GE Box
MFA in Siemens Adaptive BAS

MFA in Siemens’ APOGEE Building Automation System (BAS)

- Control supply air temp, return air temp, pressure, flow, and humidity of AHU.
- Easy configuration for various buildings, climate zones, and varying conditions…
- Controller manual tuning not required.

Benefits and Impact

- User - better comfort, energy savings.
- Siemens - technician time savings, and sharper competitive advantage.

Since 2006, about 100,000 new MFA controllers are launched by Siemens every year.
MFA in Canrig DrillSmart System

MFA Canrig’s DrillSmart Control System – MFA in NI cRIO

- MFA controls Rate of Penetration, Weight on Bit, and Differential Pressure.
- For horizontal and lateral drilling for different rigs under varying operating conditions.
- Controller manual tuning not required.

Benefits and Impact

- Safer, more efficient oil&gas well drilling.
- Much easier lateral drilling operations.
- Sharper competitive advantage.
- Major impact to world oil&gas exploration

In 2017, about 800 systems are in operation.
An off-grid CyboInverter can connect to 4 x 300W solar panels directly and produce up to 1.2KW AC power to run 9000 to 12000 Btu Inverter-Air-Conditioners, with no batteries.

A 4-channel CyboInverter is a 4-input-1-output high-speed nonlinear system with varying inputs. Very difficult to control using PID or model based control methods. MFA is the enabling tech for this.
Good Approaches and Bad Ideas

CyboSoft’s Technical Approaches
- Flares can all be different, but our solution is more generalized for easier implementation and maintenance.
- Systematic approach to address various challenges.
- Standard platform: DCS, OPC, Modbus, CyboCon MFA software.
- Specially designed MFA controllers with simple parameters.
- Easy to install, commission, and maintain.

Ideas That Can Cause the RSR Project to Fail
- Counting on slow Btu data by GC, playing with 15-min block data.
- Believing the Btu rich vent gas does not need good control.
- Designing sub-systems such as the steam control system individually without considering a total system solution.
- Assuming the PID controllers in DCS are good enough.
- Leaving no time nor budget, hoping magic happens at the last min.
Recommendations

Why Use MFA Flare Control
- Model-Free Adaptive (MFA) control is a proven control technology that has been deployed widely since 1997.
- MFA flare control system is delivered in standard platforms.
- Compliance with RSR-63.670 rules in all operating conditions.
- Substantial amount of natural gas and steam savings.
- Getting the job done quickly once and for all.
- Flexible business arrangements with quick ROI.

What to Do Next
- Stakes are high, rules are serious, and deadline is approaching.
- Do not underestimate the technical difficulties.
- Not worth fighting this alone while effective products and solutions are available.
- Leave sufficient time and budget. If needed, we are here to help.
CyboSoft Offerings

Flare Process Modeling and Control Simulation Software
- Run real-time flare process model and control simulation as a training tool for this complex process. Help design your control system or see how MFA control solution works.

MFA Flare Control Solution
- MFA flare control systems can deal with all the challenges in controlling NHVvg, NHVcz, CE, and NHVdil so the flare can comply with EPA limits in all operating conditions.
- Use CyboCon MFA control software running in a PC and interface to an existing DCS through OPC or Modbus, etc.

Flare Control Consulting and On-Site Commissioning
- Consulting for building an effective control system to comply with EPA RSR 63.670 rules. Control system design, parts selection, on-site commissioning, training, and services.
Founded in 1994, a technology company offering specialty software products and solutions.

The leader in control technology serving the worldwide process control, building control, and equipment control markets.


Our vision and mission

Provide control tech and products to address urgent market needs.

Help address the “critical threats” and contribute to the society.