# 1 Avoid Using Open System Controls on a Closed System

Consider a simple system consisting of a vessel and a pump or compressor which withdraws fluid from the vessel. The question is how best to control the machine flow. In an open system at steady state with the feedrate set by outside factors, the machine flow is adjusted to hold a constant mass inventory in the system. For a liquid, inventory is measured by level. For a vapor, inventory is measured with pressure (Fig 2 & 3).

Fig 2: Liquid – controls outlet flow w/ level
Fig 3: Vapor – controls outlet flow w/ pressure

Consider now a closed system, which has a fixed mass inventory, circulating at a given rate. (Fig 4 and 5, with the red lines converting from open to closed systems.) Fig 4 attempts to use the open loop strategy of varying pump flow to hold a level setpoint; however, the level is fixed by the inventory, so this control strategy will drive the recycle valve to either fully open or fully closed. In Fig 5, the compressor flow is controlled effectively by discharge throttling.

This illustrates a key difference between open and closed systems; they must use different strategies to control flowrates.

# 2 – “Mind the Head”: Speed Impacts More Than Flow

In LNG processes, the MR compressor type is centrifugal or axial, which both have a relationship between volumetric flowrate and head. (The pressure ratio is determined from the head.)

Fig 6 illustrates how speed affects performance. By the fan laws, the volumetric flowrate increases linearly with speed, but head increases with the square of speed. Because the amount of refrigeration supplied depends on the pressure ratio, small changes in speed can greatly affect refrigeration supplied. Therefore, in closed loop MR systems, it is more accurate to think of speed primarily affecting head, not flowrate.

# 3 Avoid Suction Pressure Control for MR Compressors

One parameter of interest is the MR compressor suction pressure. In an open system, the compressor suction pressure can be held constant by adjusting the compressor flowrate (Fig 7). However, in a closed system, the MR compressor suction pressure is a function of many things: inventory, compressor speed, the overall LNG process operation and compressor flow rate. Therefore, it is difficult to control suction pressure based on a single parameter. In particular for LNG liquefaction, attempting to control MR compressor suction pressure with just speed is not effective.

MR Compressor Controls

These learnings can be applied to the MR system of an LNG liquefaction process. The closed MR system is defined by 3 inputs. Once these are defined, all other operating parameters are fixed.

> Optimum Conditions – Constant Inventory

Dynamic simulations were performed to rigorously model a constant inventory system. Three cases were run: base (DS-1), turndown at constant speed (DS-2) and turndown with reduced speed (DS-3).

<table>
<thead>
<tr>
<th>Case</th>
<th>DS-1</th>
<th>DS-2</th>
<th>DS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>LNS Production</td>
<td>Speed</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>65%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>65%</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td>Results</td>
<td>Suction Pressure (bara)</td>
<td>4.28</td>
<td>3.78</td>
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<tr>
<td></td>
<td>Discharge Pressure (bara)</td>
<td>44.8</td>
<td>45.7</td>
</tr>
<tr>
<td></td>
<td>Compression Ratio</td>
<td>10.5</td>
<td>12.1</td>
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<tr>
<td></td>
<td>Power to recycle</td>
<td>0.0%</td>
<td>4.5%</td>
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<tr>
<td></td>
<td>MR Spec Power (relative)</td>
<td>100%</td>
<td>106.8%</td>
</tr>
</tbody>
</table>

Key results of this study:
- In DS-2 and DS-3, the MR compressor recycles to prevent surge, which increases power consumption.
- Lower speeds decreases turndown power consumption (compare DS-2 and DS-3)
  - Speed decreases only ~10 as much as production
  - Even with the small speed reduction, the head (as indicated by compression ratio) decreased significantly.

Automatically Adjusting Speed With Production

Modern LNG plants have control systems, such as the Air Products Enhanced Control Scheme (APECS) that automatically optimize performance and move the plant between different operating modes. A dynamic simulation was run, with AP-ECS automatically varying plant production from 106% to 70% and back. The AP-ECS was modified to rate the speed with the refrigeration flowrates. When the anti-surge valves open, the speed setpoint is held constant. AP-ECS automatically adjusted the JT valves and speed to keep the key operating parameters within the desired range: production, LNG temperature and MCHC warm end JT (efficiency measurement). These dynamic simulations confirm that it is possible to avoid the 3 common mistakes and also automatically adjust speed and control the process when varying production.

Conclusions

- Three facts must be considered to effectively control the MR system:
  - The MR system is closed: control concepts for an open system may not apply
  - Varying speed affects head (and refrigeration) much more than it affects flow
  - MR suction pressure cannot be controlled with a single parameter, such as speed.
- At turndown, slightly reducing MR compressor speed consumes less power by partially or completely closing the AVS.
- In the LNG liquefaction process, if the MR compressor speed is varied, then adjust the speed based on supplied refrigeration.

For Further Information

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