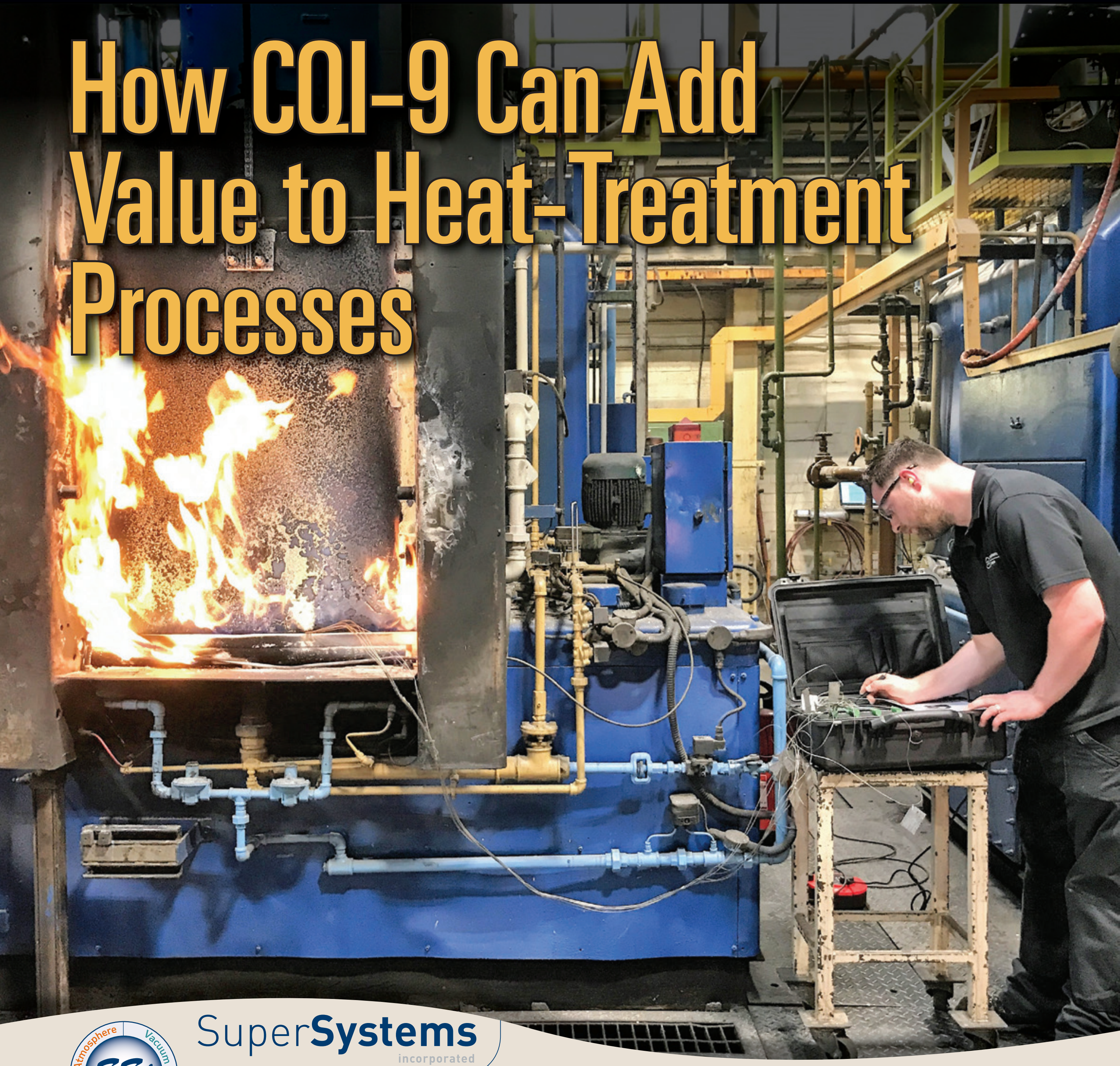
INDUSTRIAL HEATING
The International Journal of Thermal Processing
OCTOBER 2017

How CQI-9 Can Add Value to Heat-Treatment Processes



SuperSystems incorporated

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CQI-9 is implemented with varying degrees of enthusiasm in the global heat-treatment industry.

Fig. 3. Brett Hill of Super Systems Europe performs a temperature uniformity survey for a CQI-9 compliant heat treater.

Many engineers see CQI-9 as a useful quality checklist that ensures efficient and issue-free processing, while others see it as a burdensome list of requirements that wastes time and money. If the self-assessment document is treated as a box-ticking exercise, it is indeed a waste of resources. That approach essentially looks at "the letter of the law," and finds the quickest, easiest and cheapest way of fulfilling the requirements. If a "spirit-of-the-law" approach is taken, however (i.e., if the reasoning behind the requirements is fully understood and absorbed), the document can add significant value to the heat-treatment operation.

For example, many facilities employ external calibration engineers to fulfill the on-site pyrometry requirements. A letter-of-the-law approach might involve scheduling instrument calibrations, system-accuracy tests and temperature uniformity surveys per the requirements in tables 3.2.1, 3.3.1 and section 3.4. In this approach, certificates are checked and filed without detailed review or analysis in order to satisfy the requirements in the shortest time.

On the other hand, a spirit-of-the-law approach could allow for periodic management review of certification to look for patterns over time and to seek potential areas of improvement. Temperature uniformity surveys might indicate the furnace's uniformity is within tolerance but with increasingly poor recovery times and wider spreads than those found in previous surveys. Corrective action may be taken, such as implementing regular burner inspection and tuning, which may reduce the total spread and increase the throughput of the furnace by reducing heating/recovery speeds.

Instrument calibration results might be acceptable and within stated tolerances, but instrument drift may be increasing over time, which may be being compensated for with increasingly large offsets. Corrective action might include periodically replacing instrumentation or returning products to the manufacturer for factory calibration and/or refurbishment. Ultimately, this type of corrective action may reduce the likelihood of quality issues while reducing the costs associated with inefficient processing and maintenance problems. The question is how to adopt this approach in a quality-management system.

Failure Mode and Effects Analysis (FMEA and PFMEA)

Failure mode and effects analysis (FMEA), another often misunderstood requirement, is required for each process by the CQI-9 self-assessment document. If they are filled out purely to fulfill the requirement without special attention to the specific and often unique quality requirements of the process, they are again a waste of time. If properly understood and implemented, however, these procedures can serve to prevent and/or mitigate all potential safety, quality and efficiency issues with the department, process and furnace.

The AWT technical committee wrote an excellent article in the German publication *Der Wärmebehandlungsmarkt* in 2016 that defines best practice for producing a process failure-mode and effects analysis (PFMEA) for a continuous hardening furnace.[1] This article contains an excellent guide to producing a comprehensive and detailed heat-treatment-specific PFMEA using fishbone diagrams to identify process requirements.

As a manufacturer of oxygen probes, let us compare two

Reprinted from the Ocotber 2017 issue of INDUSTRIAL HEATING

PFMEAs as they relate to the potential consequences of an oxygen-probe failure during processing, using the AWT Technical Committee's guidelines.

The difference between the two PFMEAs is clear. Figure 4 does fulfill the CQI-9 requirement, but it does not consider the reason that the requirement exists. The requirement's goal is to encourage forward planning and continuous improvement in order to prevent quality issues, and this analysis stops well short of addressing that goal.

Figure 5 considers the detailed CQI-9 requirement with regard to carbon-potential tolerance and the impact of a failure on the process, on the part and on the furnace. The full impact of a failure is often only properly understood after this type of detailed analysis. The failure of relatively inexpensive components can have huge knock-on effects, which can be prevented with simple detection and preventive measures.

In the previous example, it is understood that an oxygen-probe failure can affect the atmosphere accuracy, the part hardness and can damage the furnace. If left unchecked, this issue would ultimately result in reworked or scrapped parts and furnace downtime – an expense in time, resources and finances that will far exceed the extra work required to develop and enact a more robust PFMEA.

Figure 5 forms the basis of a maintenance and continuous-improvement plan for the atmosphere-control system. It can be used as a training tool for maintenance teams that

Fig. 1. Instrument calibration requirements from CQI-9 (Table 3.2.1)

Instrument	Instrument type	Maximum calibration period (months)	Calibrated against	Calibration accuracy required	Use
Reference standard	Zener voltage reference	36	NIST or equivalent national standard	Per NIST or ISO EN standard	Limited to primary standard calibration
Primary standard	Potentiometer, digital volt meter or equivalent	36	Reference standard	±0.05°C (±0.1°F) or ±0.015% of reading, whichever is greater	Limited to laboratory calibration of secondary standard and test instruments and primary and secondary standard sensors
Secondary standard	Potentiometer, digital volt meter or equivalent	12	Primary standard	±0.2°C (±0.3°F) or ±0.05% of reading, whichever is greater	Limited to laboratory calibration of field test instruments, system accuracy test sensors, temperature uniformity survey test sensors, load sensors and controlling, monitoring or recording sensors
Field test instrument	SAT/TUS portable potentiometer or digital instrument, electronic data recorder or data acquisition system	12	Primary or secondary standard	±0.6°C (±1.0°F) or ±0.1% of reading, whichever is greater	Limited to controlling, monitoring or recording instrument calibration, performance of system accuracy tests and temperature uniformity surveys
Control, monitoring or recording instruments	Digital instrument electro mechanical instrument	3	Field test instrument (single-point or multi-point calibration)	±2.0°C (±4.0°F)	Limited to measuring, recording and controlling the temperature of thermal-processing equipment
		6 (1)	Primary standard (multi-point calibration)		
Control, monitoring or recording instruments	Mechanical (analog) or thermal element	3	Field test instrument (single-point or multi-point calibration)	±2.0°C (±4.0°F)	Limited to measuring the temperature of refrigeration and quench-bath thermal-processing equipment
		6 (1)	Primary standard (multi-point calibration)		

1. Semi-annual calibration is allowed provided that the instrument is calibrated with a primary standard (multi-point calibration) and the SAT is performed quarterly per Method A (See 3.3.4.1). See glossary for definitions of single-point calibration and multi-point calibration.

Fig. 2. CQI-9's pyrometry standards exist to ensure the thermocouple readings as displayed on control instrumentation indicate accurate temperatures by ensuring all instrumentation is traceable to a highly accurate reference standard.

Method	SAT sensor type	Required SAT testing frequency	Maximum SAT difference allowed
Probe method	Types B, R and S noble metal; Types K, N, J and E base metal	Quarterly	±5.0°C (±10.9°F) (1,3)
Comparative method	Types B, R and S noble metal; Types K, N, J and E base metal	Monthly	±1.0°C (±2.0°F) (2,3)

1. Maximum value of the calculated SAT difference (see 3.3.4.1.3 and 3.3.4.2.5). 2. Maximum deviation from initial delta (see 3.3.4.3.2). 3. Total offset/bias assigned to the correction of a SAT error shall not exceed 2.0°C (4.0°F). This permissible offset/bias is separate from offset/bias assignable to a calibration error or TUS.

may not fully appreciate the demanding requirements of thermochemical processes.

The same approach is applied to control thermocouples in Figure 6.

If this level of detail is applied to the entire process, the PFMEA becomes a highly valuable, daily-use reference document that is constantly revised and updated as operators, engineers, maintenance and management gain experience in optimizing the process.

Risk Elimination

PFMEAs can also eliminate causes of high commercial risk. To cite a simple real-world example, during a recent training session on this subject, a management team observed the potential for quarantined parts to be mixed with finished parts during the production of a PFMEA relating to the loading of a furnace. The simple corrective action – using color-coded bins – potentially prevented a serious quality issue for the company. A letter-of-the-law approach would not have dug deep enough to discover this potential issue.

There are, of course, many other examples of how a deeper understanding of the requirements in CQI-9 can improve the overall quality of the heat-treatment process. Experience shows that investing additional time in understanding the requirements can have disproportionate positive returns in the long term.

Reference:

1. Sommer, P., Rentrop, B., Schiefer, P., Wäscher A., “Process PFMEA for Heat Treatment Processes,” THE HEAT TREATMENT MARKET (2016) 4, p. 5-17

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Fig. 4. A PFMEA relating to an oxygen-probe failure during processing

Process Requirement	Potential Failure Mode	Potential Effect of Failure	Severity (0-10)	Potential Cause	Likelihood of Occurrence (0-10)	Detection Method	Likelihood of Detection (0-10)
Atmosphere control	Oxygen probe failure	Incorrect atmosphere	4	Broken ceramic	1	Alarm	10

Fig. 5. A second PFMEA relating to an oxygen-probe failure during processing

Process Requirement	Potential Failure Mode	Potential Effect of Failure	Severity (0-10)	Potential Cause	Likelihood of Occurrence (0-10)	Prevention Method	Detection Method	Likelihood of Detection (0-10)	Recommended Actions
Control Carbon Potential to +/- 0.05 CP%	Oxygen probe sensor failure	Process: mV rise and CP% reads low causing inaccurate/false CP% reading. Part: High hardness readings and hard spots. Furnace: Soot gathering on belt, insulation, in oil bath.	8	Burn-off/reference air pump failure, installation error, contamination, mechanical damage.	3	Redundant probe installed in furnace and toggled to in case of failure. Backup checks with calibrated 3-gas analyzer. Regular chart review, annual visual Inspection.	Alarm system	9	Add oxygen probe to critical spares list. Implement regular alarm tests and consider SMS/Email messages for critical alarms to ensure.

Fig. 6. A PFMEA relating to an control-thermocouple failure during processing

Process Requirement	Potential Failure Mode	Potential Effect of Failure	Severity (0-10)	Potential Cause	Likelihood of Occurrence (0-10)	Prevention Method	Detection Method	Likelihood of Detection (0-10)	Recommended Actions
Temperature control to within +/-10°C of setpoint.	Control thermocouple failure	Process: TC should fail high so temperature will drop and alarm. Loss of temperature below lower limit. Part: Failure to meet specified time/temperature curve.	8	Oxidation, overheated, lifetime reached, contamination/chemical attack, mechanical damage, installation error.	3	Replace control TC per CQI-9. Regular maintenance of protection tubes.	Alarm system (with regular tests) and chart recording monitoring. Annual visual inspection.	9	Simulate TC failure annually. Check that controller fails high, check alarm function, check operator response, check maintenance response and spare.