industry: heat treatment
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WATLOW® Powered by Possibility

Thermal Loop Solutions:

A Path to Improved Performance, Sustainability and Compliance in Heat Treatment

Introduction:

Heat treatment processes are a crucial component of many manufacturing industries, and thermal loop solutions have become increasingly popular for achieving improved temperature control and consistent outcomes. A thermal loop solution is a closed-loop system with several essential components, including an electrical power supply, power controller, heating element, temperature sensor and process controller. The electrical power supply provides the energy needed for heating, the power controller regulates the power output to the heating element, the heating element heats the material and the temperature sensor measures the temperature. Finally, the process controller adjusts the power output to maintain the desired temperature for the specified duration, providing better temperature control and consistent outcomes.

Performance Benefits

Heat treatment thermal loop solutions offer several advantages over traditional heat treatment methods, including improved temperature control and increased efficiency. The thermal loop system provides precise temperature control, enabling faster heating and cooling and optimized soak times. In addition, the complete design of modern thermal loop solutions includes energy-efficient heating and overall ease of use.

Heat treatment thermal loop solutions are integrated with Industry 4.0 frameworks and data management systems to provide real-time information on performance. Combining artificial intelligence and machine learning algorithms can also provide additional performance benefits, such as the ability to analyze data and identify patterns for further optimization. Ongoing performance losses in a heat treatment system typically come from process drifts. Industry 4.0 solutions can explore these drifts and provide opportunities to minimize these deviations.

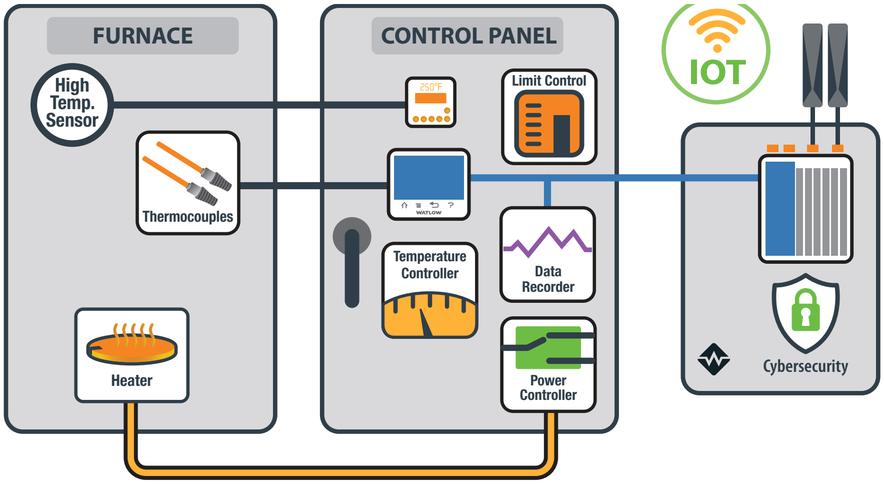


Figure 1. Watlow Industry 4.0 solutions

Heat treatment thermal loop solutions can be optimized using failure mode and effects analysis (FMEA). FMEA is a proactive approach to identifying potential failure modes and their effects, allowing organizations to minimize the risk of process disruptions and improve the overall efficiency of their heat treatment processes. Historically this was a tabletop exercise conducted once per year with a diverse team from across the organization. Updates to this static document were infrequent and were primarily based on organization memory rather than being automatically populated in real time with actual data. There is a potential to produce 'live' FMEAs utilizing today's technology and leveraging insights for continuous improvement.

The effectiveness of heat treatment thermal loop solutions can be measured using metrics such as overall equipment effectiveness (OEE). OEE combines metrics for availability, performance and quality to provide a comprehensive view of the efficiency of a manufacturing process. By tracking OEE and contextual data, organizations can evaluate the effectiveness of their heat treatment thermal loop solutions and make informed decisions about optimizing their operations.

Sustainability

Heat treatment thermal loop solutions provide several sustainability benefits, including reduced energy consumption and waste. The power controller regulates the power output to minimize energy waste, and the possible integration with renewable energy sources and circular economy principles provide a complete power solution that spans from element design to recycling and renewables. The thermal loop solutions, in combination with insulation design and materials, provide energy-efficient solutions that contribute to sustainability and reduce the environmental impact of heat treatment processes.

When discussing these systems in the context of greenhouse gas emissions and their environmental impact, it is essential to consider ***Scopes 1, 2*** and ***3***, as well as the less common ***Scope 4***:

Scope 1 **(Direct Emissions):** Heat treatment processes often involve the combustion of fossil fuels like natural gas, propane or oil to generate heat. These direct emissions are attributed to the equipment used in the heat treatment process, such as furnaces and ovens. Efforts to reduce Scope 1 emissions include upgrading to more efficient equipment or adopting alternative heating technologies, like induction or electric heating systems.

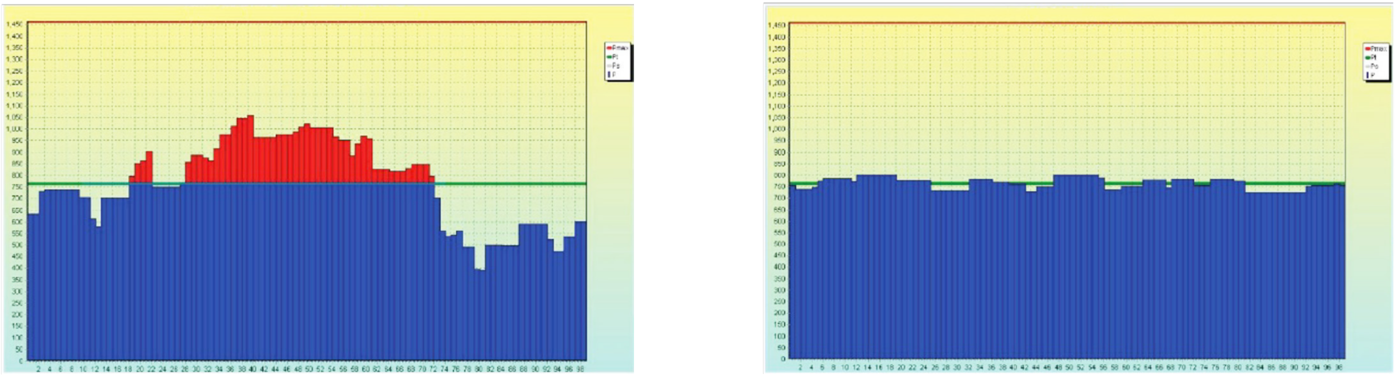
Scope 2 **(Indirect Emissions from Energy):** In heat treatment processes and thermal loop systems, electricity is often used to power various components, such as pumps, fans and control systems. The emissions associated with generating this electricity are considered Scope 2 emissions. To reduce Scope 2 emissions, companies can improve energy efficiency, invest in renewable energy sources or purchase green energy from their utility provider.

Scope 3 **(Other Indirect Emissions):** These emissions are associated with activities throughout the value chain of heat treatment applications and thermal loop systems, such as the manufacturing and transporting of raw materials, equipment and waste management. Companies can work to reduce Scope 3 emissions by collaborating with suppliers to improve the environmental performance of their products and services, optimizing transportation and logistics and implementing waste reduction strategies.

Scope 4 **(Avoided Emissions):** In heat treatment applications and thermal loop systems, avoided emissions may come from implementing energy-efficient technologies, waste heat recovery systems or other innovative solutions that reduce overall energy consumption and associated emissions. By quantifying these avoided emissions, companies can showcase the positive impact of their sustainability efforts on reducing their carbon footprint. Avoided emissions can also be highlighted when subcontracting heat treatment requirements to a more energy-efficient source rather than running a captive operation. In this approach, the heat treatment process is outsourced to an external, specialized heat treatment service provider, especially if the in-house equipment is due to be lightly utilized. These service providers operate independent heat treatment facilities and offer services to multiple clients across various industries and generally run 24x7 with high utilization.

At the component level, energy savings can be realized using current technology. Advanced SCRs provide predictive load management functions and hybrid firing algorithms and contribute to sustainability by optimizing the energy usage of heat treatment processes. These SCRs offer real-time monitoring and control of energy consumption, while predictive load management systems use specific algorithms to manage peak power loads and adjust to optimize for local conditions (load shedding or load sharing). Hybrid firing systems use a combination of firing methods to control power factors and reduce the negative impact on the electrical infrastructure.

Without "Efficient Power" (Non Synchronized) | With "Efficient Power"



Without load management costly power peaks can occur

With **Eurotherm** Predictive Load Management, power demand is balanced

Figure 2. **Eurotherm® *EPower*** predictive load management

Heater design is also essential. Switching time impacts heater life with fast, modern switching modes (hybrid firing) significantly extending heater life compared to slower switching from conventional mechanical contactors.

Systems can be rapidly tested, simulated and modeled through computational engineering. Several thermal loop systems today have improved temperature uniformity due to these methods.

Watlow's Adaptive Thermal Systems® (***ATS™***) technologies are the next frontier of thermal loop solutions. Rather than selecting the best-of-breed components, sometimes with overlapping functionality and kitting a complete solution – ***ATS*** provides a merged design between heater and control systems. ***ATS*** is already in place in several semiconductor applications, and this type of technology is looking to scale into heat treatment applications shortly.

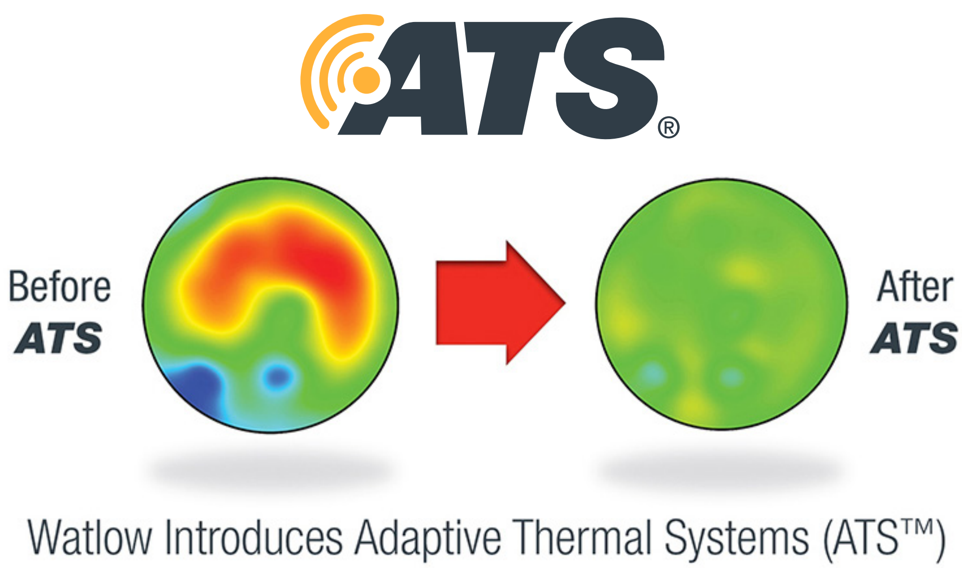


Figure 3. Watlow Adaptive Thermal Systems® (***ATS™***)

Regulatory Compliance

Nadcap (National Aerospace and Defense Contractors Accreditation Program) is an industry-driven program that provides accreditation for special processes in the aerospace and defense industries. Heat treatment is considered a “special process” under Nadcap because it has specific characteristics crucial to aerospace and defense components’ quality, safety and performance. These characteristics include:

Process sensitivity: Heat treatment processes involve precise control of temperature, time and atmosphere to achieve the desired material properties. Minor variations in these parameters can significantly change the mechanical and metallurgical properties of the treated components. This sensitivity makes heat treatment a critical process in the aerospace and defense industries.

Limited traceability: Heat treatment processes typically result in changes to the material’s microstructure, which are not easily detectable through visual inspection or non-destructive testing methods. This limited traceability makes it crucial to have strict process controls to ensure the desired outcome is achieved consistently.

Critical performance requirements: Aerospace and defense components often have strict performance requirements due to the extreme conditions in which they operate, such as high temperatures, high loads or corrosive environments. The heat treatment process ensures that these components meet the specifications and can withstand these demanding conditions.

High risk: The failure of a critical component in the aerospace or defense sector can result in catastrophic consequences, including loss of life, significant financial loss and reputational damage. Ensuring that heat treatment processes meet stringent quality and safety standards is essential to mitigate these risks.

Nadcap heat treatment accreditation ensures suppliers meet industry standards and best practices for heat treatment processes. The accreditation process includes rigorous audits, thorough documentation and ongoing process control monitoring to maintain high quality, safety and performance levels.

The aerospace industry’s AMS2750TMG pyrometry specification and the automotive industry’s CQI-9 Issue 4 regulations are crucial for ensuring consistent and high-quality heat-treated components. Adherence to these regulations is essential for meeting the stringent quality requirements of the aerospace and automotive industries and other industries with demanding specifications.

Temperature uniformity is a crucial requirement of both AMS2750G and CQI-9 Issue 4, mandating specific temperature uniformity requirements for heat-treating furnaces to ensure the desired mechanical properties are achieved throughout the treated components. AMS2750G Class 1 Furnaces with strict uniformity requirements +/-5°F (+/-3°C) provide both quality output with predictable energy use. However, maintaining this uniformity requires significant maintenance oversight due to all the components involved in the thermal loop.

Calibration and testing procedures are specified in the standards to help ensure the accuracy and reliability of the temperature control systems used in heat-treating processes.

Detailed process documentation is required by AMS2750G and CQI-9 Issue 4, including temperature uniformity surveys, calibration records and furnace classifications. This documentation ensures traceability, enabling manufacturers to verify that the heat-treating process is consistently controlled and meets the required specifications.

Figure 4. **Eurotherm** Data Reviewer

Modern data platforms enable the efficient collection of secure raw data (tamper-evident) and provide the replay and reporting necessary to meet the standards. The newer platforms also offer the latest industry communication protocols (MQTT / OPC UA) to ease data transfer across enterprise systems.

> MQTT is a lightweight, publish-subscribe-based messaging protocol for resource-constrained devices and low bandwidth, high latency or unreliable networks. IBM developed it in the late 1990s, and it has become a popular choice for IoT applications due to its simplicity and efficiency. MQTT uses a central broker to manage the communication between devices, which publish data to “topics” and subscribe to topics they want to receive updates on.
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> OPC UA (Open Platform Communications Unified Architecture) is a platform-independent, service-oriented architecture (SOA) developed by the OPC Foundation. It provides a unified framework for industrial automation and facilitates secure, reliable and efficient communication between devices, controllers and software applications. OPC UA is designed to be interoperable across multiple platforms and operating systems, allowing for seamless integration of devices and systems from different vendors.

The importance of personnel and training is emphasized by CQI-9 Issue 4, which requires manufacturers to establish training programs and maintain records of personnel qualifications to ensure that individuals responsible for heat-treating processes are knowledgeable and competent. With touch screens and mobile integration, a significant development in process controls has occurred over the last decade.

Continuous improvement is also emphasized by both AMS2750G and CQI-9 Issue 4, requiring manufacturers to establish a system for monitoring, measuring and analyzing the performance of their heat treatment systems. This development enables manufacturers to identify areas for improvement and implement corrective actions, ensuring that heat-treating processes are continuously improving and meeting the necessary performance and safety standards.

By integrating these regulations into a precision control loop, heat treatment thermal loop solutions can provide the necessary level of control and ensure compliance with AMS2750G and CQI-9 Issue 4, leading to the production of high-quality, heat-treated components that meet the performance required and safety standards.

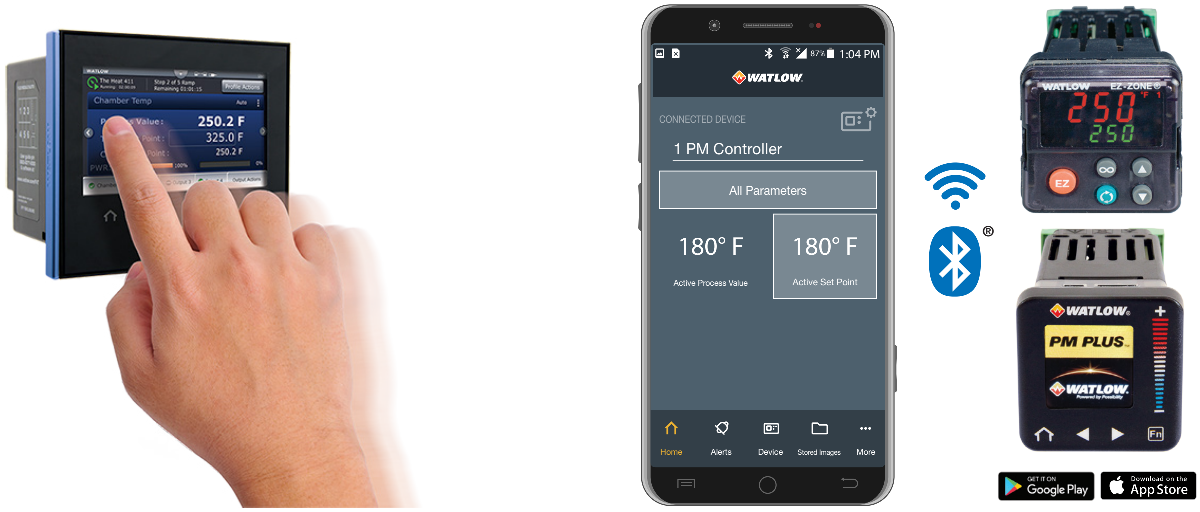

Figure 5. Watlow F4T® touch-screen controller and ***Watlow PM PLUS®*** with ***EZ-LINK™*** mobile application

Challenges and Limitations

The initial investment in heat treatment thermal loop solutions can sometimes be higher than in traditional methods. However, this investment often leads to a significantly lower total cost of ownership and improved return on investment due to the thermal loop solutions' increased efficiency, improved quality control and extended life.

Ensuring regulatory compliance is complex and time-consuming, requiring organizations to have the right people, processes and equipment.

Future Trends

As Industry 4.0 and digital transformation continue to gain momentum and Industry 5.0 practices are implemented, heat treatment thermal loop solutions will become increasingly important. Integrating digital technology and machine learning algorithms will provide even greater control, traceability and transparency, enabling organizations to make informed decisions based on real-time data and predictive analytics. In addition, as new materials and manufacturing processes are developed, adaptive and flexible heat treatment thermal loop solutions will need to evolve to meet these challenges and provide the necessary level of control and efficiency for these new applications.

Conclusion

Heat treatment thermal loop solutions provide several benefits over traditional heat treatment methods, including improved temperature control, increased efficiency and improved sustainability outcomes. The integration with Industry 4.0 and data management systems, as well as the use of FMEA and OEE metrics, further help enhance the performance of heat treatment processes. As Industry 4.0 digital transformation and Industry 5.0 practices continue to evolve, heat treatment thermal loop solutions will play an increasingly important role in the future of heat treatment.

Further information is available at: www.watlow.com