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DIFHEMI

DIRECT FLUID HEATING BY ELECTROMAGNETIC INDUCTION

High-Efficiency Thermal-Fluid Heating for the Plastics & Flexible Packaging Industry

DIFHEMI Induction Heating vs. Conventional Electrical Resistance Heating

A practical technical overview of where heat is used, how thermal oil systems work, and where DIFHEMI can provide an alternative to conventional heating.

The central idea

DIFHEMI is not simply another electrical resistance heater. It is a direct fluid-heating system based on electromagnetic induction, designed to generate heat in the heating assembly through which the process fluid flows. For plants using thermal oil, the technology can be considered as a central heat generator feeding the existing thermal-fluid circuit. Arrhenius Coking Screening, Preliminary Kinetic Model and Reduced-Order CFD-Style Thermal Analysis.

FERRO ALLOYS - SILICON CARBIDE
SILICON METAL - PIG IRON
METALLURGICAL CONSULTANT

+39 339 734 7133
2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
info@aaconsultrade.com
www.aaconsultrade.com

1. Executive Summary

Plastic processing plants use heat at several stages: polymer melting and plasticisation in the extruder, temperature control of dies, heated rolls and calenders, laminating and coating equipment, tanks and reactors, and other auxiliary process equipment. The heating technology is therefore not necessarily the same throughout the plant, typical thermal-fluid users include heated rolls, calenders, laminators, coating systems, jacketed tanks, reactors and selected extrusion or die-heating circuits. In these applications, thermal oil can provide stable and uniform heat distribution over a broad temperature range.

Extruder barrels are commonly heated by electrical band heaters, ceramic heaters or other electrically heated zones. However, many plastic-film and flexible-packaging plants operate thermal-fluid circuits to supply controlled heat to rolls, calenders, laminators, coating units, tanks, reactors and other equipment.

This is where DIFHEMI becomes particularly relevant. Instead of generating heat by combustion, or by conventional electrical resistance immersed in or directly associated with the fluid-heating process, DIFHEMI uses electromagnetic induction to heat the metallic heating assembly and transfer heat directly to the circulating fluid.

DIFHEMI is a direct fluid-heating system based on electromagnetic induction. Electrical energy generates heat in the metallic tubes of coils heating assembly through which the thermal fluid circulates. The system therefore heats the process fluid without a burner and without conventional resistance elements immersed in the fluid stream.

The potential benefits include high energy efficiency, rapid thermal response, accurate temperature control, reduced maintenance, elimination of combustion at the heater, and a heating configuration designed to reduce the risk of localised overheating of the thermal fluid. The actual performance and energy savings must, of course, be established for each installation from its duty, flow rate, temperatures, pressure and existing system.

This technical paper extends the previous DIFHEMI plastics-industry thermal-fluid review by providing a quantitative assessment of thermal-fluid degradation and coking tendency, together with a reduced-order CFD-style comparison between DIFHEMI induction heating and conventional electrical resistance heating. Although the present study uses thermal oil in plastics processing as the reference case, the same fundamental heat-transfer and kinetic principles can be applied to other carbonaceous fluids, including mineral and synthetic oils, petroleum-derived liquids, fuels, hydrocarbons and natural gas (NG), whenever localized overheating may promote thermal degradation, cracking, fouling, carbonaceous deposits or coking. The fundamental advantage of the

DIFHEMI concept is therefore not limited to thermal-oil applications: by controlling the fluid-to-wall temperature difference and reducing localized high-temperature exposure, induction heating can reduce the conditions that promote thermal degradation and deposit formation in a broad range of temperature-sensitive carbonaceous fluids.

The specific degradation mechanisms, kinetic parameters and critical film temperatures will vary according to the chemical composition of each fluid; therefore, application-specific validation is required when extending the model beyond the thermal-oil reference case.

For the calculations presented below, a representative high-temperature synthetic heat-transfer fluid is used: a biphenyl/diphenyl-oxide eutectic fluid of the Therminol VP-1 type. The manufacturer describes VP-1 as a biphenyl/diphenyl oxide eutectic mixture with a maximum recommended bulk-use temperature of 400°C. This fluid was selected because its composition is publicly defined and its high-temperature property data are available, making it useful for transparent engineering screening.

For DIFHEMI, the principal design assumption requested for this study is a wall-to-fluid temperature difference of 25°C. Thus, for a representative 320°C outlet bulk-fluid condition, the corresponding induction tube-wall/film temperature is approximately 345°C. The resistance-heater cases are treated as screening scenarios rather than universal values because actual resistance-element and local film temperatures depend strongly on watt density, geometry, flow, fouling and control.

2. Where Heat Is Used in Plastic-Film Production

A simplified film-production route is:

Plastic pellets → Hopper → Extruder → Die → Cooling → Draw/Orientation → Heated rolls / calender → Winding

The extruder normally contains several temperature zones. Polymer pellets are conveyed by the screw through the heated barrel, where they are melted and homogenised before reaching the die. Depending on the process and machine design, heat may be supplied by electrical heaters, thermal oil or a combination of heating and cooling.

Potential thermal-fluid users within the plant

- Heated rolls and temperature-controlled rolls
- Calender rolls and finishing rolls
- Laminators
- Coating and adhesive systems
- Process tanks and resin/adhesive tanks

+39 339 734 7133
2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
info@aaconsultrade.com
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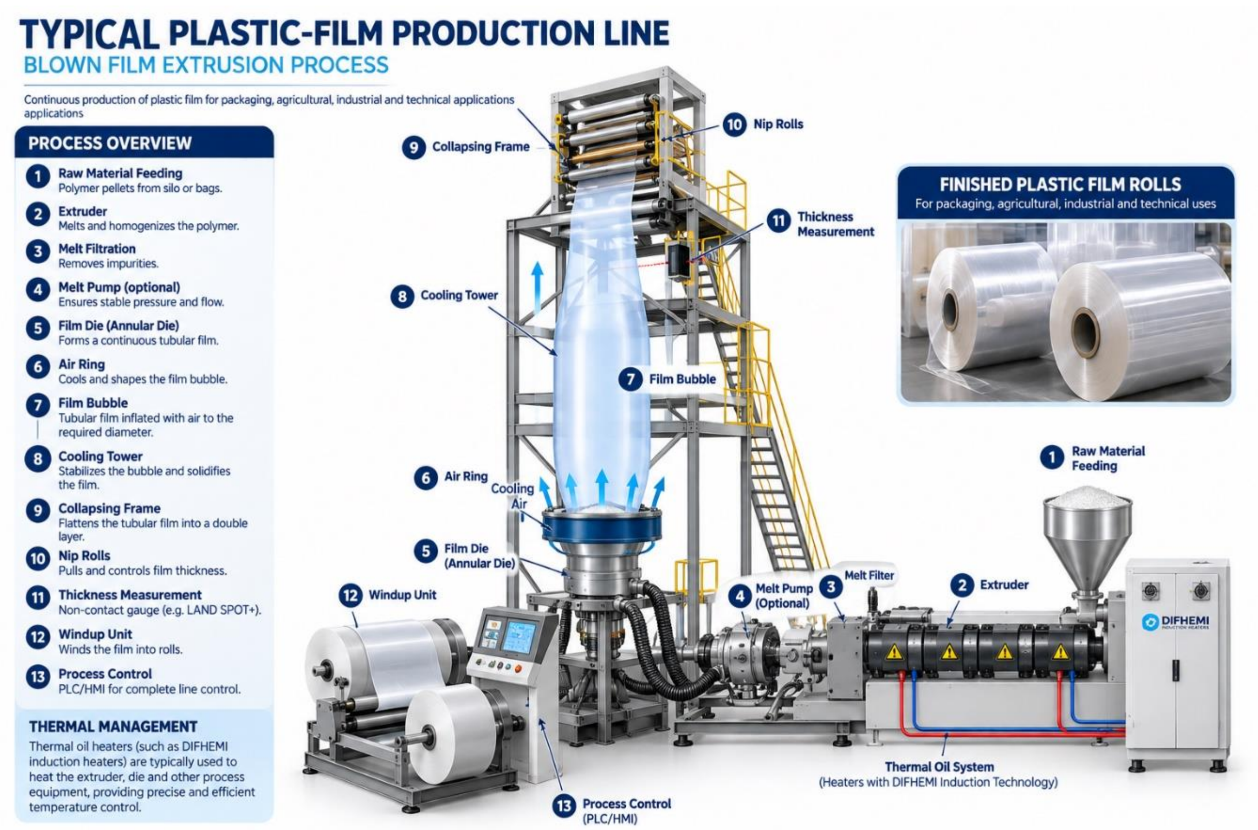
- Reactors and jacketed vessels
- Central thermal-oil distribution circuits
- Selected extruder or die-heating systems when specifically designed for thermal fluid

FIGURE 1 — Typical plastic-film production line



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SILICON METAL - PIG IRON
METALLURGICAL CONSULTANT

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2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
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FIGURE 2A — Thermal-oil circuit serving several plastic-processing machines

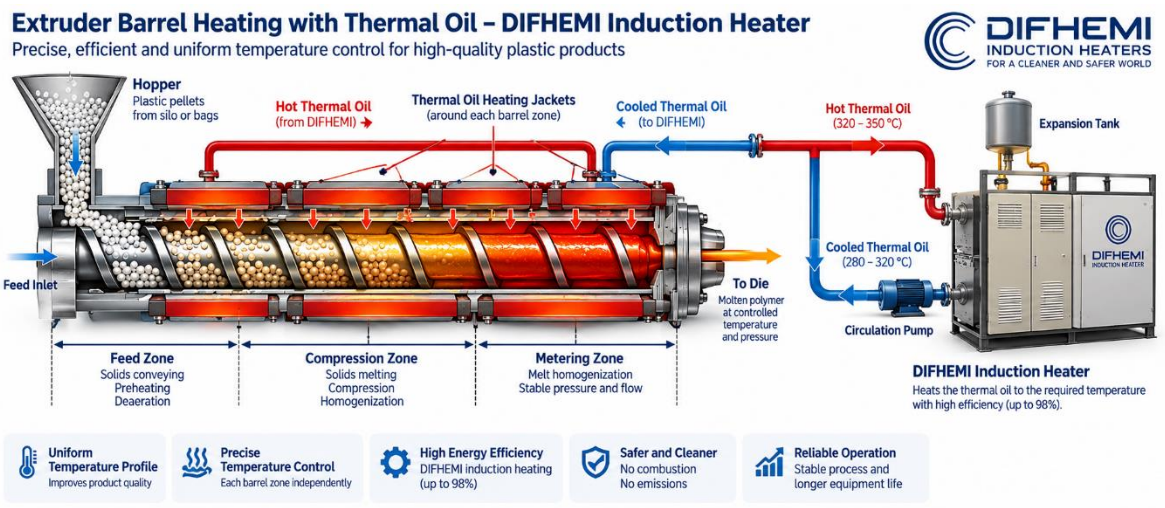
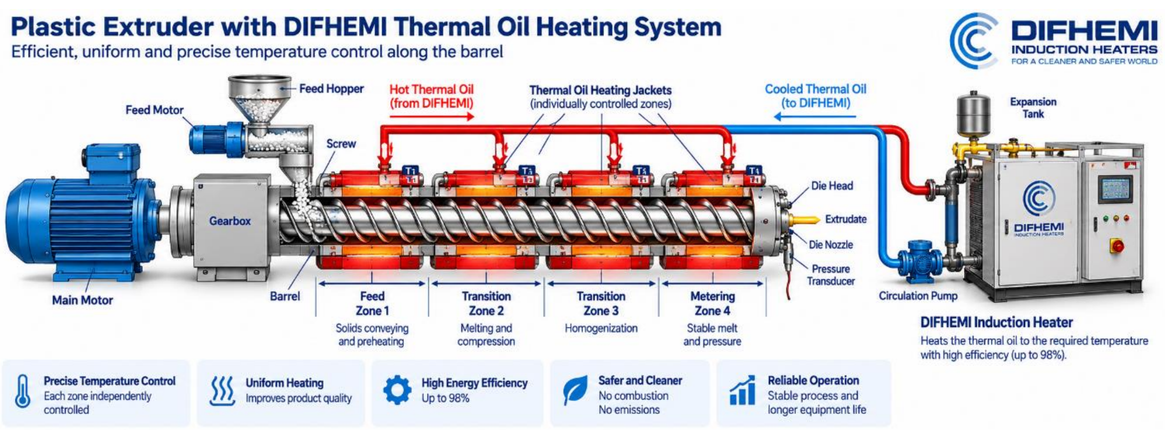


FIGURE 2B — Thermal-oil circuit serving several plastic-processing machines



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3. Conventional Heating Technologies

3.1 Electrical resistance heaters

Band heaters, mica heaters and ceramic heaters are widely used around extruder barrels. They can provide high local heat flux and are well established in plastics processing. Ceramic constructions may have element/surface-temperature ratings far above the normal polymer-processing temperature. For example, certain ceramic band heaters are specified in the 500–700 °C range, although this does not mean that the plastic is processed at 700 °C.

Typical polymer-processing temperatures are substantially lower and depend on the material and grade. Indicative ranges include approximately 160–250 °C for conventional PE/PP applications, 170–250 °C for many ABS/PS/PVC applications, 250–300 °C for PET, 240–300 °C for many PA grades, and above 300 °C for selected engineering polymers. Actual values must always be taken from the polymer supplier and machine/process specification.

3.2 Steam and combustion-based systems

Steam can be an effective industrial heat-transfer medium, but a steam-based installation requires a boiler or steam source, water treatment, steam distribution, condensate management and associated equipment. Where thermal oil is the required process medium, a steam system may also require a heat exchanger to transfer energy to the oil.

Gas, diesel and other combustion systems can provide large thermal duties, but they require burners, combustion controls, exhaust systems and associated safety and maintenance infrastructure. They also introduce combustion emissions at the heat source.

4. What Is DIFHEMI and HOW it WORK?

DIFHEMI stands for Direct Fluid Heating by Electromagnetic Induction. The principle is to use electromagnetic induction to generate heat in the metallic heating assembly while the process fluid flows through the heating tubes. The electrical energy is therefore converted into heat at the heating unit, with direct transfer to the circulating fluid.

Technology is particularly suitable for thermal oils and other industrial fluids where controlled temperature, continuous circulation and reliable operation are important.

DIFHEMI is based on the same fundamental electromagnetic principle used in an electrical transformer. Instead of heating a fluid indirectly through combustion, steam or conventional electrical resistance elements, DIFHEMI uses electromagnetic induction to generate heat directly in the metallic tube assembly through which the process fluid flows.

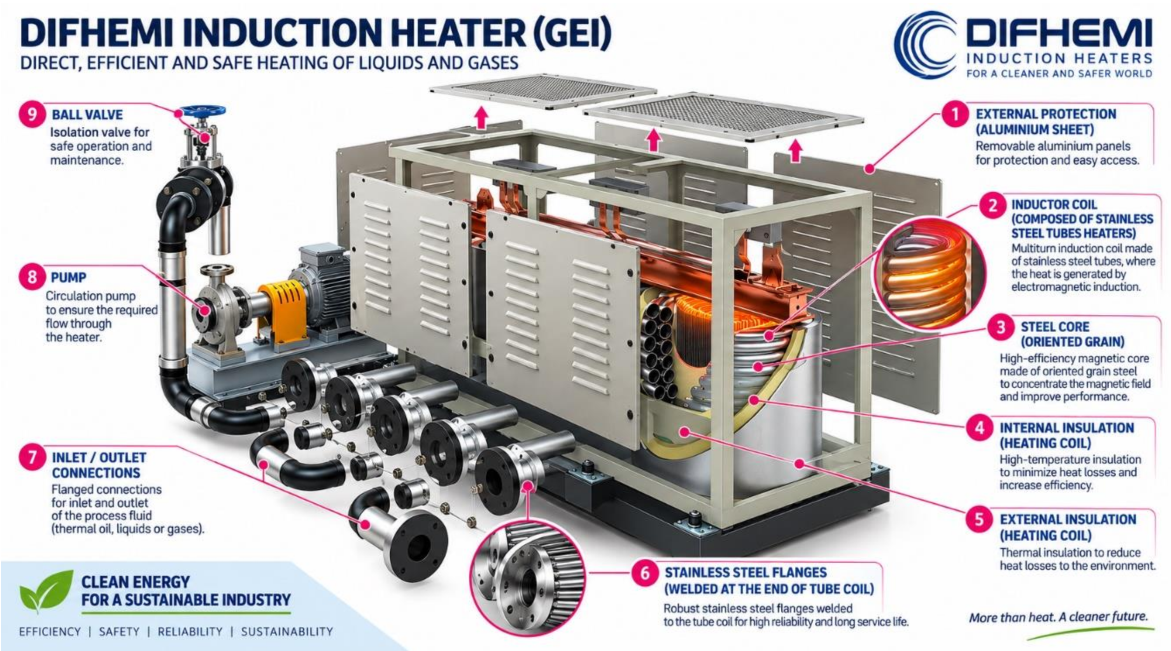
Electrical power is supplied to induction coils, creating an alternating electromagnetic field. This field induces electrical currents in the metallic heating tubes, causing the tube walls themselves to generate heat. The circulating fluid continuously absorbs this heat as it passes through the internal tube circuit. Because the heat is generated directly in the metallic surface in contact with the flowing fluid, DIFHEMI eliminates the need for a flame, combustion chamber or intermediate steam circuit. There are also **no conventional electrical resistance elements in contact with the fluid**.

An important characteristic of this principle is the ability to control the temperature difference between the tube wall and the circulating fluid. Combined with continuous fluid movement, this provides a more uniform thermal field and reduces localized overheating and hot-spot formation—particularly important for temperature-sensitive and carbonaceous fluids susceptible to thermal degradation, fouling or coking.

DIFHEMI can be engineered for both **liquids and gases**, including thermal oils, mineral and synthetic oils, petroleum-derived fluids, fuels, natural gas and other industrial process fluids, according to the required temperature, pressure, flow rate and thermal duty.

In essence, DIFHEMI converts electrical energy into useful process heat **directly where the heat transfer to the fluid occurs**, providing a compact, controllable and highly efficient single-stage fluid-heating system.

FIGURE 3 — Difhemi internal view

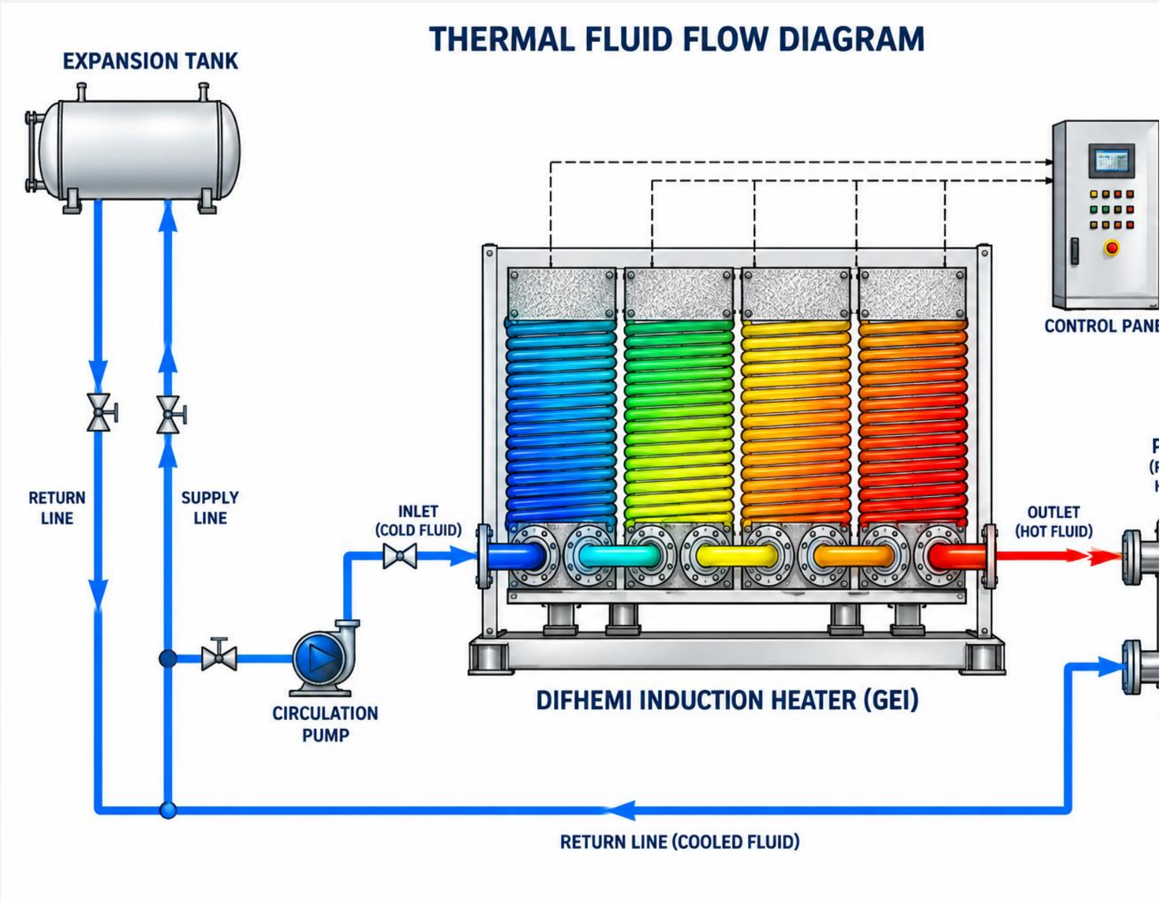


The operating principle can therefore be summarized in a single energy-transfer sequence:

Electrical Energy → Electromagnetic Field → Heated Tube Wall → Process Fluid

The fluid enters the DIFHEMI at the required inlet pressure and flow rate, circulates through the internal tube bundle, progressively absorbs heat from the inductively heated tube walls, and leaves the heater at the specified outlet temperature.

FIGURE 4 — DIFHEMI operating principle



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SILICON METAL - PIG IRON
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info@aaconsultrade.com
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5. DIFHEMI Compared with Conventional Heating

Aspect	Electrical Resistance	Steam / Combustion	DIFHEMI
Heat generation	Resistive element	Boiler / burner / heat exchanger	Electromagnetic induction
Thermal fluid	Can be heated by resistance system	May require heat exchanger	Directly heated in the induction heating assembly
Combustion	No	Normally yes for fired boiler	No combustion at heater
Maintenance	Element ageing/replacement	Burner, boiler and auxiliary equipment	Designed for reduced heater maintenance
Thermal response	Good, depending on mass and control	Depends on boiler/system inertia	Rapid response due to low thermal inertia of the heating assembly
Local overheating risk	Can occur if surface heat flux is high	Depends on exchanger/burner design	Designed to reduce localized overheating risk
Installation	Often distributed at machine zones	Central boiler + distribution	Compact heater feeding a thermal-fluid circuit
Temperature control	Good with suitable controls	Good with suitable controls	Precise control possible with electrical power modulation
Emissions at heater	No combustion emissions	Combustion emissions	No combustion emissions

This comparison is qualitative. The correct choice depends on the process, required temperature, thermal duty, operating hours, electricity and fuel costs, existing infrastructure, safety requirements and the condition of the current heating system.

6. Thermal Oil: Temperature Limits and High-Temperature Fluids

There is no single maximum temperature for 'thermal oil'. The allowable temperature depends on the fluid chemistry, system design and operating conditions. Two values are particularly important: the bulk temperature of the circulating fluid and the maximum film temperature at the heating surface.

The film temperature can be significantly higher than the average circulating-oil temperature. This is why heater design, flow velocity, heat flux and temperature distribution are critical to fluid life.

Manufacturer	Fluid	Type	Indicative max. bulk temperature	Potential DIFHEMI application
Eni	Alaria 3 HT	High-performance mineral	320 °C	High-temperature thermal-oil circuits
Shell	Heat Transfer Oil S2	Mineral	320 °C	Thermal-fluid process heating
Castrol	Perfecto HT 5	Mineral	320 °C	High-temperature process circuits
Paratherm	Paratherm HE	Treated mineral	Up to ~332 °C with non-fired heaters	Plastics, polymers, textiles
Eastman	Therminol 66	Synthetic	345 °C	High-temperature polymer/process systems

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Eastman	Therminol 68	Synthetic	360 °C	High-temperature liquid-phase systems
Eastman	Therminol 72	Synthetic	380 °C	Ultra-high-temperature systems
Eastman	Therminol VP-1	Synthetic	Up to ~400 °C	Calender rolls, extrusion, PET and other processes
Dow	DOWTHERM A	Synthetic organic	Up to ~400 °C	High-temperature process heating
Dow	SYLTHERM 800	Silicone	Up to ~400 °C	High-temperature liquid-phase heat transfer

The values above are indicative manufacturer specifications and must be checked against the current technical data sheet, system configuration and application

7. Practical Temperature Ranges for DIFHEMI Applications

Temperature	Category	Typical DIFHEMI opportunity
150–250 °C	Common process range	Many conventional thermal oils and synthetic fluids; rolls, calenders, tanks, reactors and coating.
250–320 °C	Very relevant range	High-quality mineral fluids and synthetic fluids; many plastic and polymer processes.
320–360 °C	High-temperature range	Typically calls for carefully selected high-temperature synthetic fluids and system design.
360–400 °C	Special high-temperature range	Requires specific fluid selection, circulation, expansion/pressure design, materials and safety engineering.

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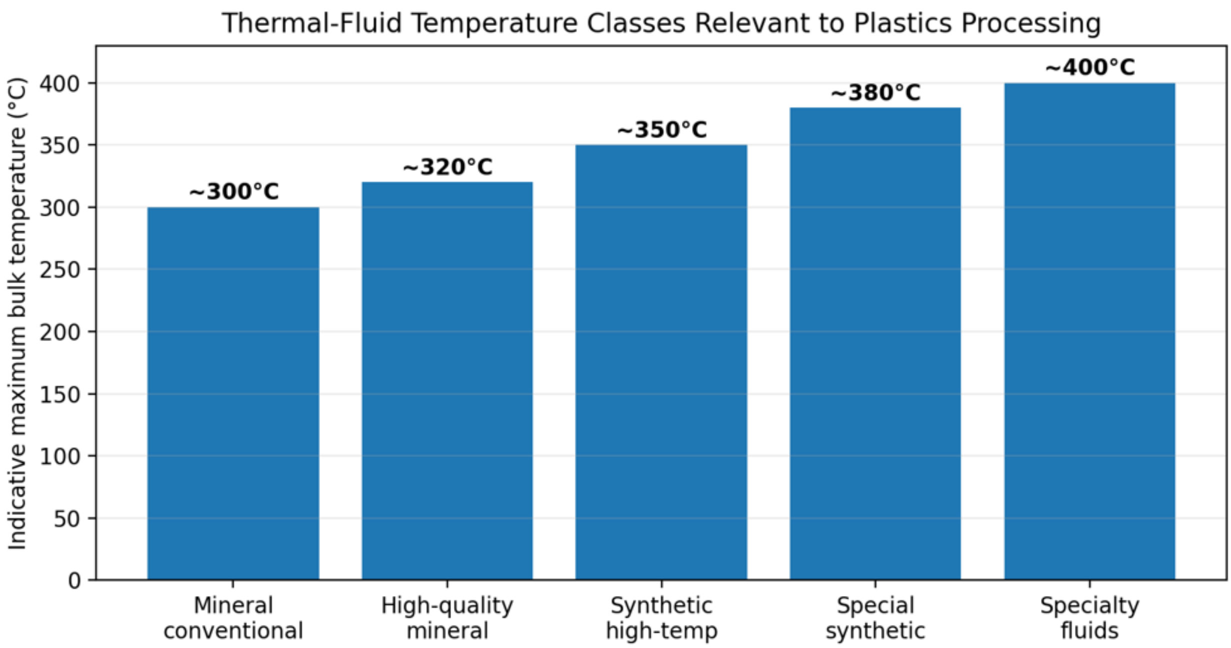

Figure 4 – Indicative thermal-fluid temperature classes. Always confirm the current fluid manufacturer limits.

8. Why DIFHEMI Is Particularly Interesting for Thermal Oil

High electrical-to-thermal efficiency: DIFHEMI is designed for very efficient conversion of electrical energy into useful thermal energy. The final efficiency of a plant depends on the complete system, including pumps, insulation, controls and distribution.

Direct fluid heating: Heat is generated in the induction heating assembly and transferred directly to the circulating fluid, avoiding a separate combustion chamber and, where applicable, avoiding an additional primary heat exchanger.

Reduced local overheating risk: The system is designed around controlled heat transfer to the flowing fluid. Correct sizing of flow, heat flux and temperature limits remains essential.

Fast thermal response: The heating assembly has low thermal inertia compared with large fired boilers, enabling rapid response to changes in process demand.

Precise control: Electrical power can be modulated to match the process requirement, supporting accurate outlet-temperature control.

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2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
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Reduced maintenance: The heater contains no burner or conventional immersed heating elements; the electrical power electronics and auxiliaries remain service items.

No combustion at the heater: There is no flame or combustion process at the DIFHEMI heater, which can simplify the heating area and eliminates combustion emissions at the point of heat generation.

Compact installation: A DIFHEMI unit can be positioned as a central thermal-fluid heater close to the process or integrated into an existing thermal-oil circuit, subject to engineering review.

24/7 industrial operation: The technology is intended for continuous industrial service when properly sized and operated.

9. Example: Replacing a Conventional Thermal-Oil Heater

Consider, purely as an illustrative example, a film or flexible-packaging plant requiring approximately 1,000–2,000 kW of thermal duty in its thermal-oil circuit. The existing system could be a fired thermal-oil boiler, or an electrical resistance-based heater.

Existing fired system:

Fuel → Burner → Thermal-oil heater → Pump → Distribution → Rolls / Calender / Laminator / Tanks → Return

DIFHEMI concept:

Electricity → DIFHEMI → Hot thermal oil → Pump → Distribution → Rolls / Calender / Laminator / Tanks → Return

The objective is not necessarily to replace every electrical heater on every machine. In many plants, the more attractive project is to replace the central source of heat for an existing thermal-oil network while leaving the downstream users and controls substantially unchanged, subject to a detailed engineering assessment.

10. Technical Comparison

Parameter	DIFHEMI induction thermal-fluid heater	Conventional electric-resistance thermal-fluid heater
Heat-generation principle	Electromagnetic induction heats the metallic heating assembly	Electrical resistance element generates heat
Heating surface used in this paper	Tube/heating wall controlled at bulk +25°C	Element/sheath surface above bulk temperature; actual ΔT depends on design
Contact with fluid	Fluid flows through the induction-heated tube assembly	Fluid receives heat from resistance-element sheath / heater surface

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Local hot-surface sensitivity	Designed for controlled wall temperature and distributed heat transfer	Can be sensitive to local watt density, low flow, fouling and element geometry
Residual heat after power reduction	Low thermal inertia of the induction-heated assembly supports rapid response	Depends on element mass, sheath temperature and heater construction
Combustion	None	None
Temperature control	Electrical power modulation with fluid-temperature feedback	Electrical power modulation / staged elements with fluid-temperature feedback
Maintenance focus	Power electronics, instrumentation, pump and fluid circuit	Resistance elements, contactors/power controls, instrumentation, pump and fluid circuit
Thermal-oil protection objective	Keep wall/film temperature close to required bulk temperature	Requires careful watt-density and flow design to prevent excessive local surface temperature

Relative Coking Rate – Arrhenius-Type Screening

Thermal degradation and deposit formation in organic heat-transfer fluids accelerate strongly as local film/surface temperature increases. For comparative screening, the relative reaction-rate constant is represented by the Arrhenius relation:

$$k = Ae^{-E_a/(RT)}$$

For a ratio between two temperatures, the pre-exponential factor A cancels. Ea is the assumed apparent activation energy, R is the universal gas constant (8.314 J/mol·K), and T is absolute temperature in kelvin. Consistent with the earlier screening approach, Ea = 180 kJ/mol is retained as a mid-case engineering assumption. This is not a measured kinetic constant for Therminol VP-1 and therefore the results are comparative indices, not a prediction of actual coke mass or fluid lifetime.The earlier draft contained relative-rate values that are not mathematically consistent with the stated Arrhenius equation and Ea = 180 kJ/mol. They have therefore been recalculated here. The DIFHEMI reference is 345°C film temperature (320°C bulk + 25°C wall-to-fluid difference), assigned a relative rate of 1.0.

Case	Bulk / process basis	Hot surface / film temp.	Relative Arrhenius rate vs. 345°C
DIFHEMI – baseline	320°C bulk + 25°C	345°C	1.0×
Resistance – moderate	screening case	375°C	5.1×
Resistance – elevated	screening case	400°C	17.5×
Resistance – near VP-1 film limit	screening case	430°C	69×
Resistance – extreme / above VP-1 recommended film limit	screening case	450°C	162×

The exponential sensitivity is the central result: even a seemingly modest increase in local film temperature can increase the screening degradation rate by an order of magnitude or more. This is why local hot spots matter more than the average bulk-oil temperature. A 430°C local film temperature is approximately 69 times the 345°C reference rate under the stated kinetic assumption.

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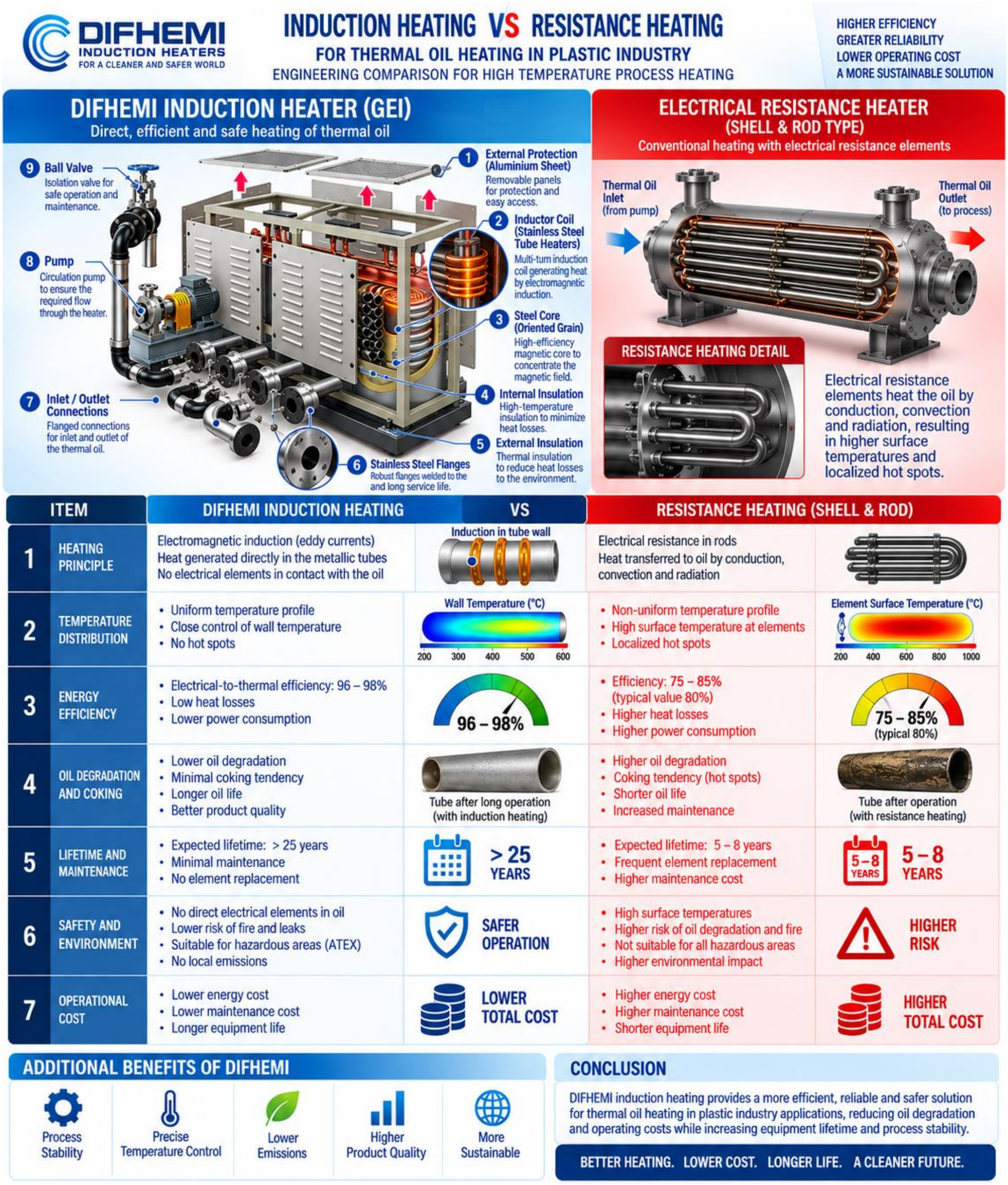
FIGURE 5 — Comparition table Induction vs. resistances



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11. Preliminary Kinetic Model Structure

For the representative biphenyl/diphenyl-oxide thermal fluid, a simplified first-order degradation structure is used. The model does not claim to reproduce the proprietary detailed chemistry of commercial fluid. Instead, it represents the main engineering pathways relevant to heater comparison:

- Parent heat-transfer molecules → lighter degradation products (thermal cracking / low boilers).
- Parent molecules and radicals → heavier aromatic products (high boilers).
- Heavy products → insoluble deposits / coke under severe local temperature and residence-time conditions.
- Each pathway is represented by $k_i(T) = A_i \exp(-E_{a,i}/RT)$, with temperature taken at the local fluid film adjacent to the heating surface.
- The heater comparison therefore depends primarily on the local temperature field, wall-to-fluid gradient, residence time and heat-flux distribution.

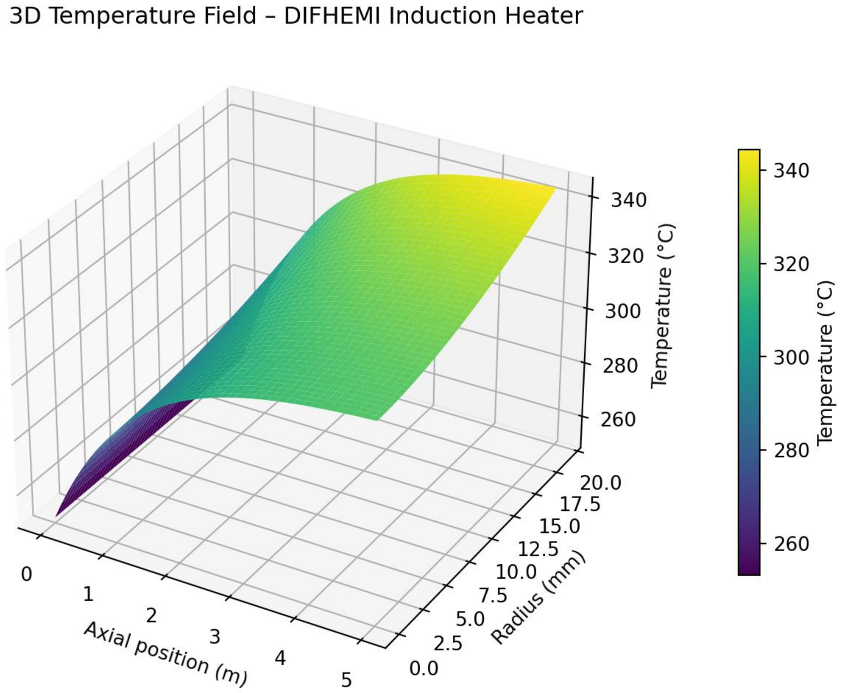
The representative fluid is not modelled as a single pure compound. It is treated as a two-component aromatic eutectic (biphenyl + diphenyl oxide) with lumped degradation products. This is adequate for preliminary comparative thermal-risk screening but not for detailed fluid-life prediction.

12. Reduced-Order CFD-Style Model Basis

The following figures are reduced-order engineering simulations intended to visualize the physical differences between the two heating concepts. They are not full ANSYS/Fluent CFD or finite-element calculations. The model uses an equivalent 5 m heated flow length and a 19 mm characteristic radius, with thermal oil increasing from approximately 250°C to 320°C.

- DIFHEMI: local tube-wall temperature follows the bulk-fluid temperature with a maximum wall-to-fluid approach of 25°C.
- Resistance heater: the same general bulk-heating duty is represented, but with a strongly concentrated near-wall/local hot-surface field to illustrate the effect of resistance-element heat-flux concentration.
- Heat-flux and thermal-stress maps are comparative screening fields. The stress figures are MPa-equivalent relative indices, not FEA-certified stresses.
- The model is steady-state and axisymmetric/reduced-order; it does not resolve full serpentine geometry, turbulence, electromagnetic field coupling, contact resistances or detailed heater construction.

13. CFD Thermal Analysis



The DIFHEMI field shows a smooth axial temperature rise and a controlled radial gradient. At the outlet, the model approaches 320°C bulk and approximately 345°C at the tube wall.

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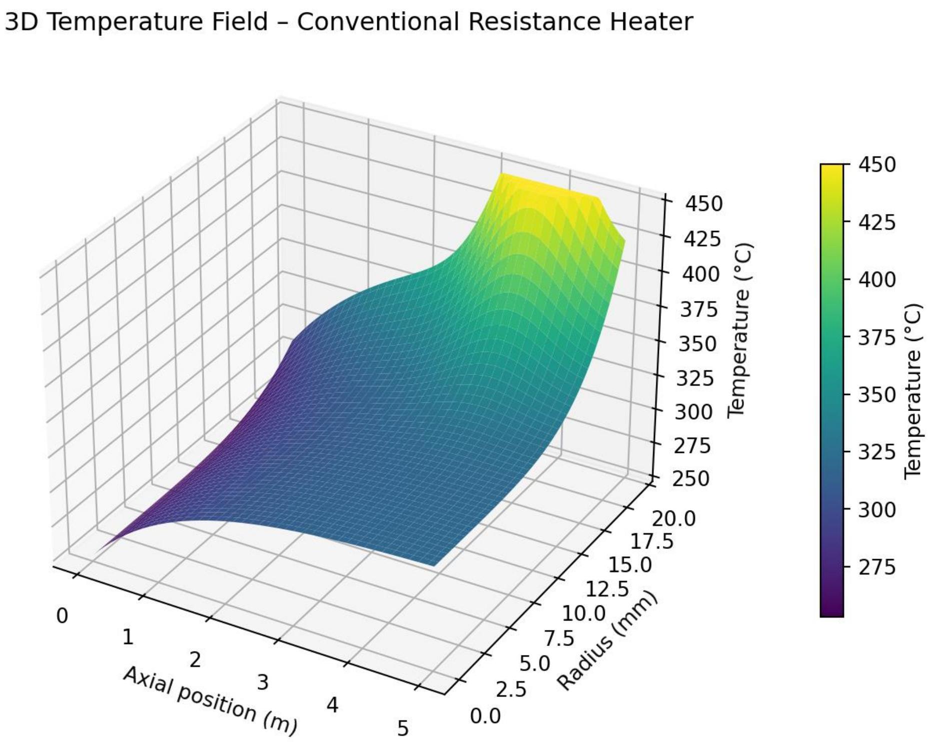

Figure 2. CFD_3D_Resistance_units

The resistance-heater screening field shows a much steeper near-wall temperature rise and a localized hot region. The bulk process duty remains comparable, while local surface temperature becomes the dominant degradation driver.

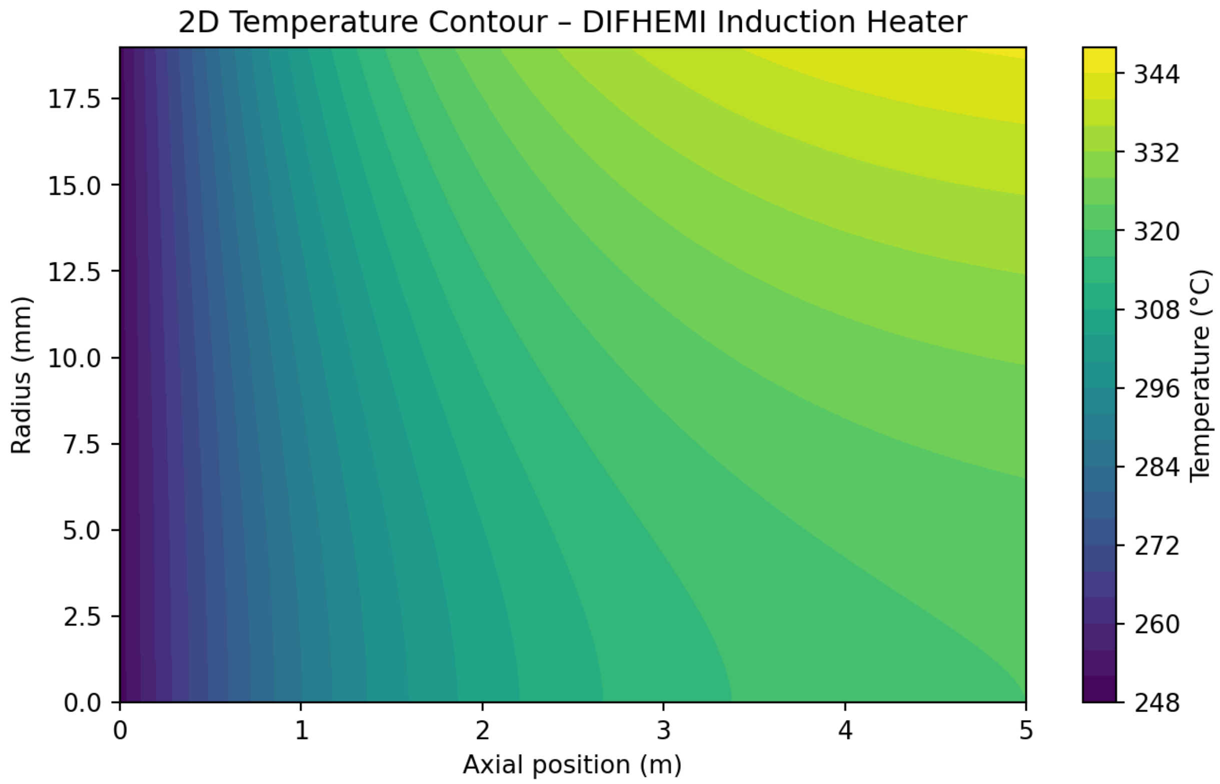

Figure 3. CFD_2D_Induction_units

The 2D contour highlights the comparatively uniform induction-heating field and the specified 25°C maximum wall-to-fluid approach.

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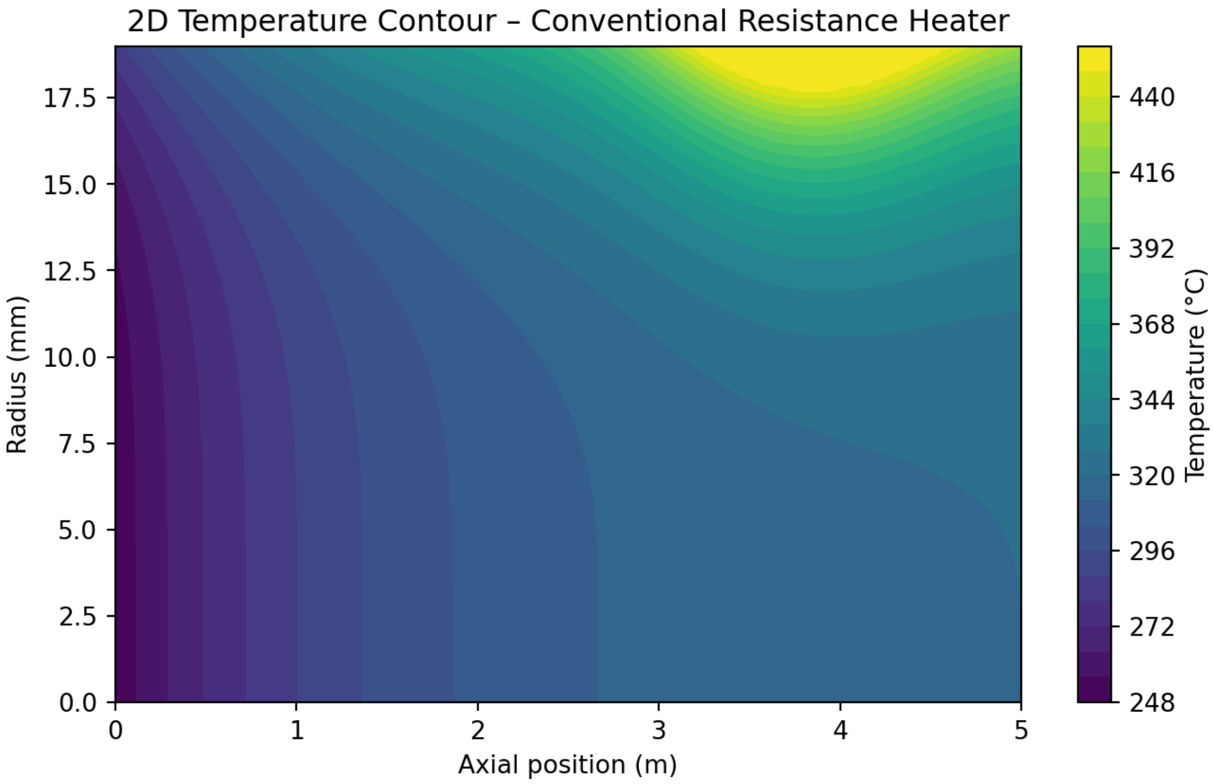

Figure 4. CFD_2D_Resistance_units

The resistance case develops a concentrated high-temperature zone near the heating surface. This is the condition that can accelerate thermal-fluid degradation even when average outlet temperature is acceptable.

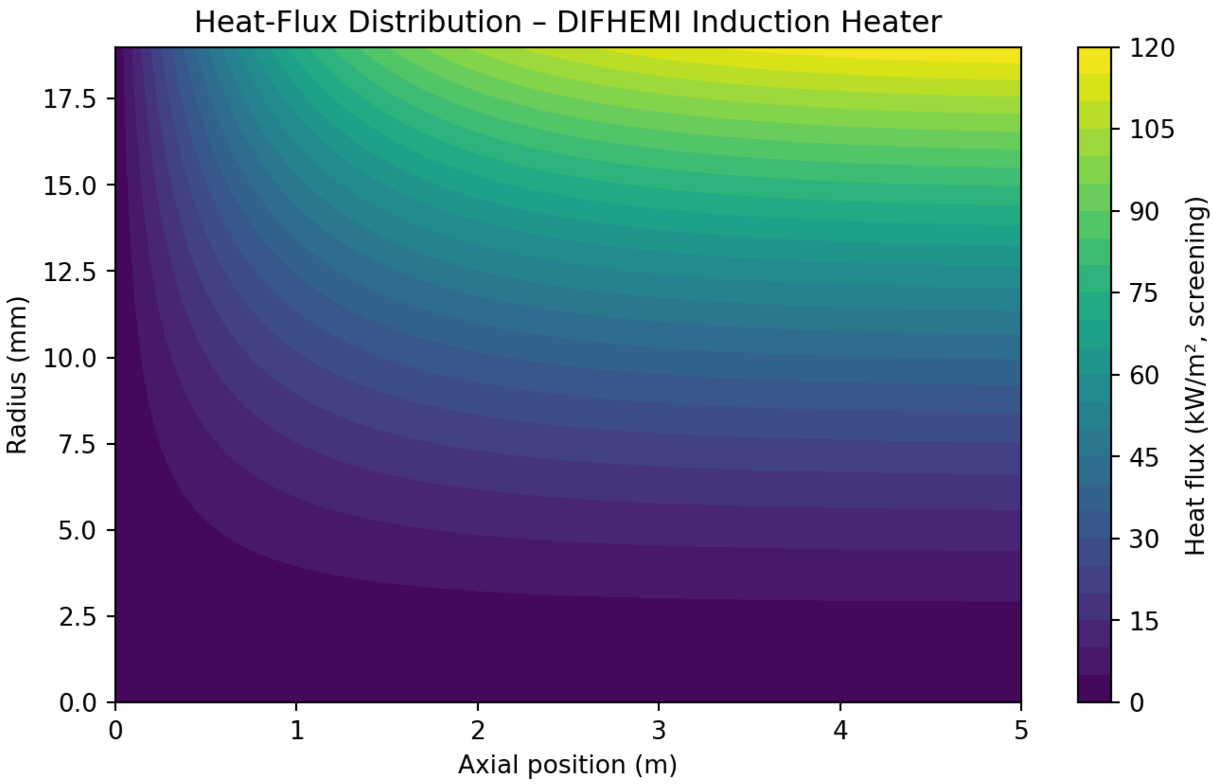

Figure 5. CFD_heatflux_induction

The induction heat-flux screening map is normalized to a representative maximum of approximately 120 kW/m² and shows a comparatively distributed heating pattern.

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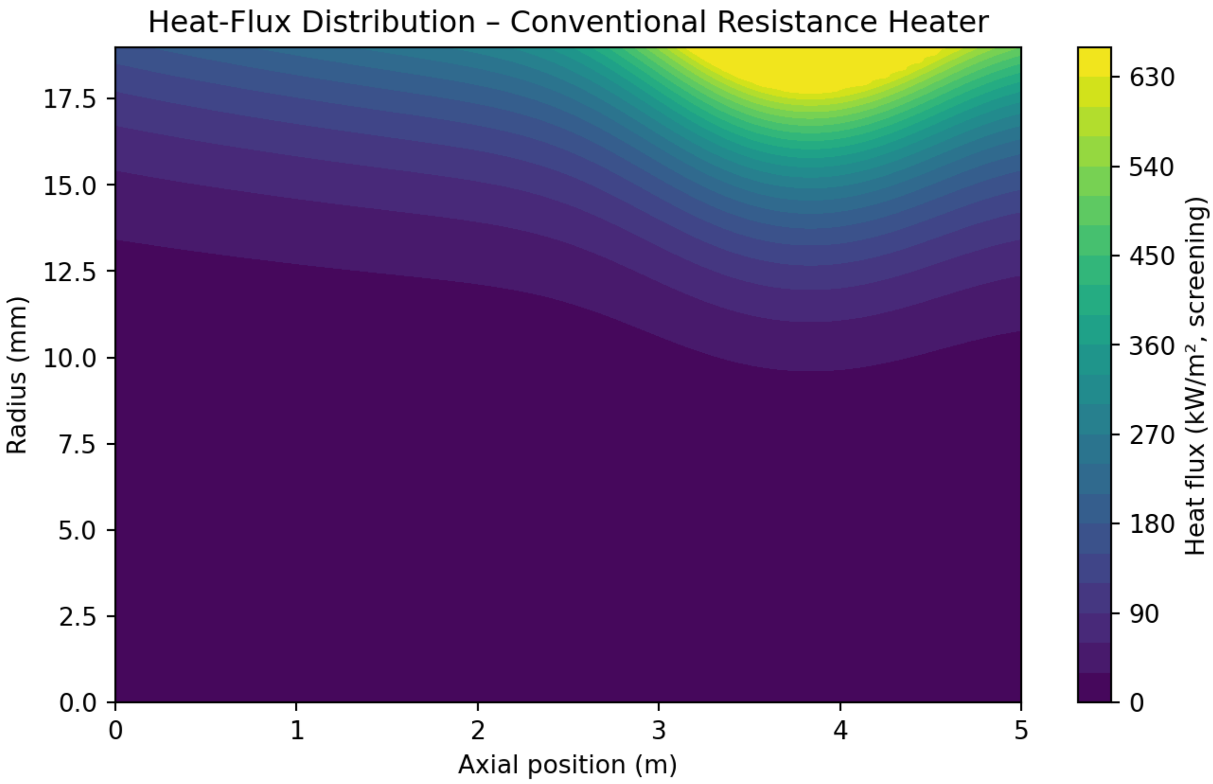

Figure 6. CFD_heatflux_resistance

Using the same normalization basis, the resistance case shows significantly greater local heat-flux concentration. Actual values must be calculated from the real element watt density and geometry.

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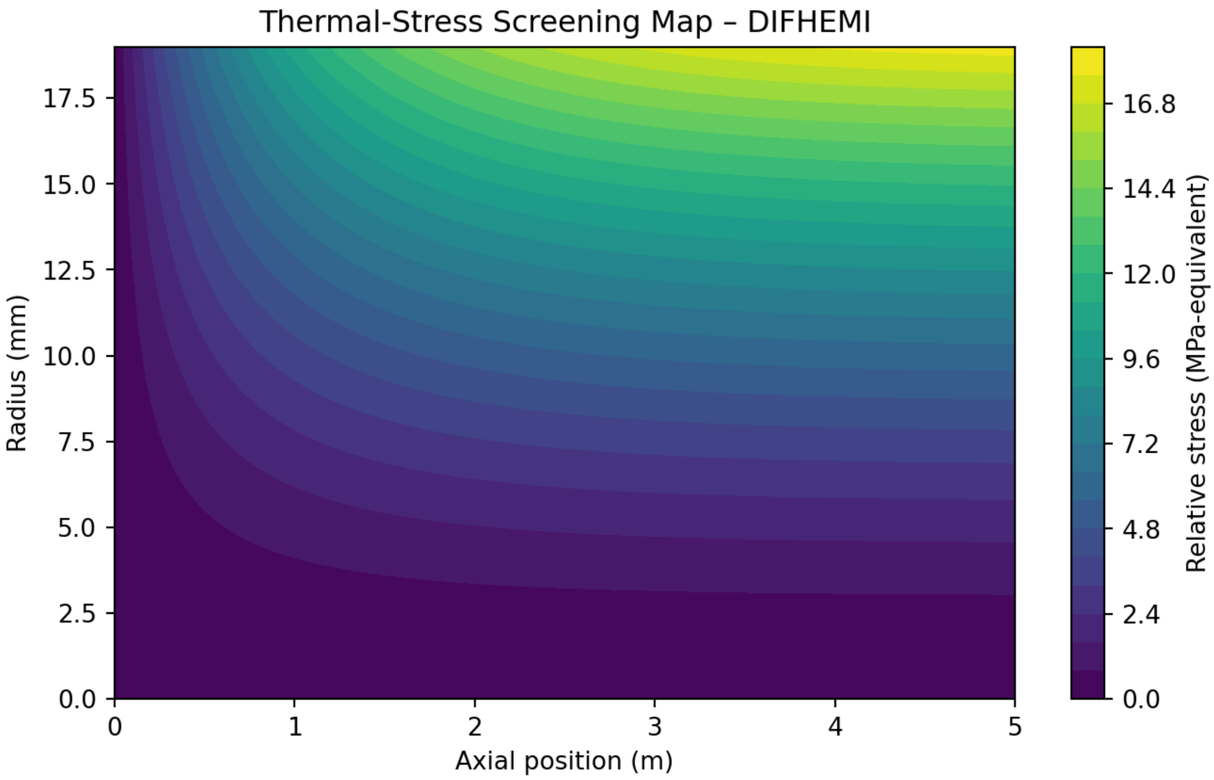

Figure 7. CFD_stress_induction

The induction thermal-stress screening map follows the lower radial temperature gradient. It should be interpreted comparatively, not as a certified mechanical stress result.

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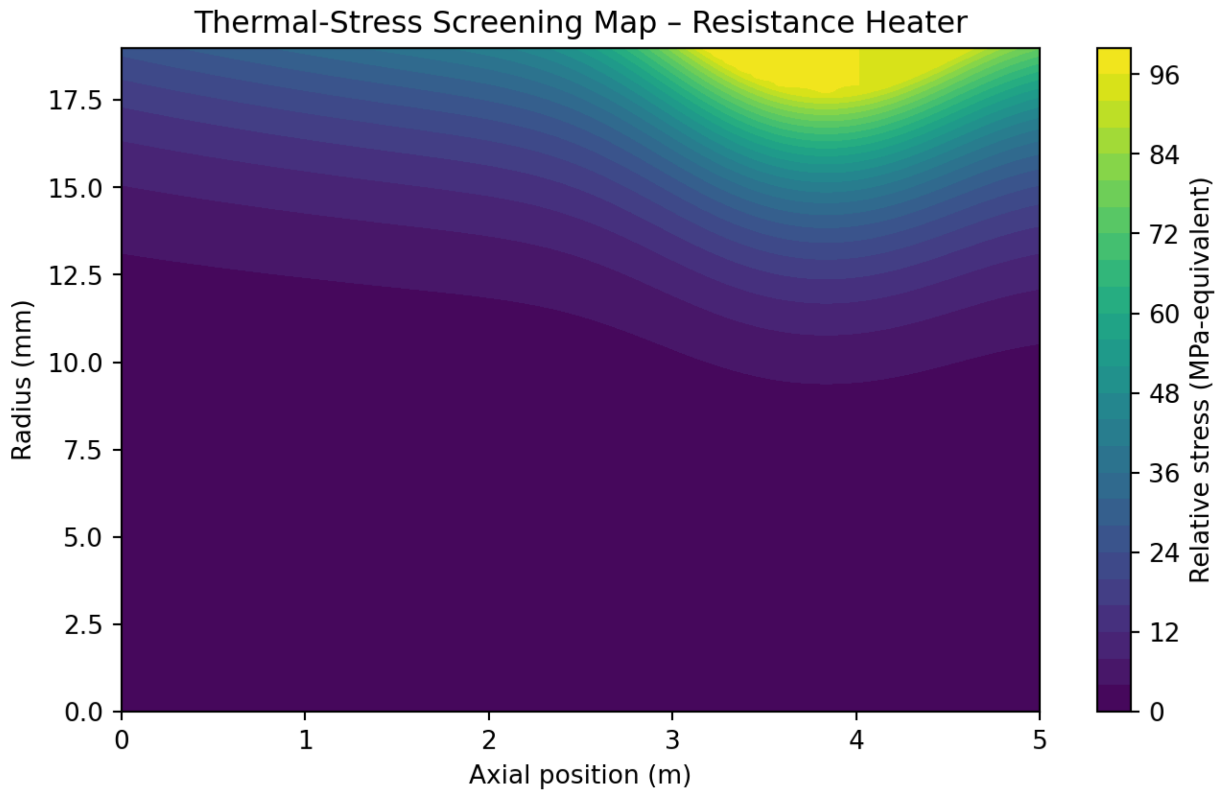

Figure 8. CFD_stress_resistance

The resistance-heater map shows substantially higher local thermal-stress index in the hot-surface region because thermal gradients are more concentrated.

14. Long-Term Thermal Exposure and Creep Screening

At the 250–400°C thermal-oil temperatures relevant to many plastics processes, classical high-temperature creep of a suitable metallic heater alloy may not be the governing damage mechanism; thermal cycling, local overheating, oxidation, fluid degradation and fouling can be more important. Figures 9 and 10 are therefore presented as normalized long-term thermal-exposure / creep-screening indices rather than material life predictions.

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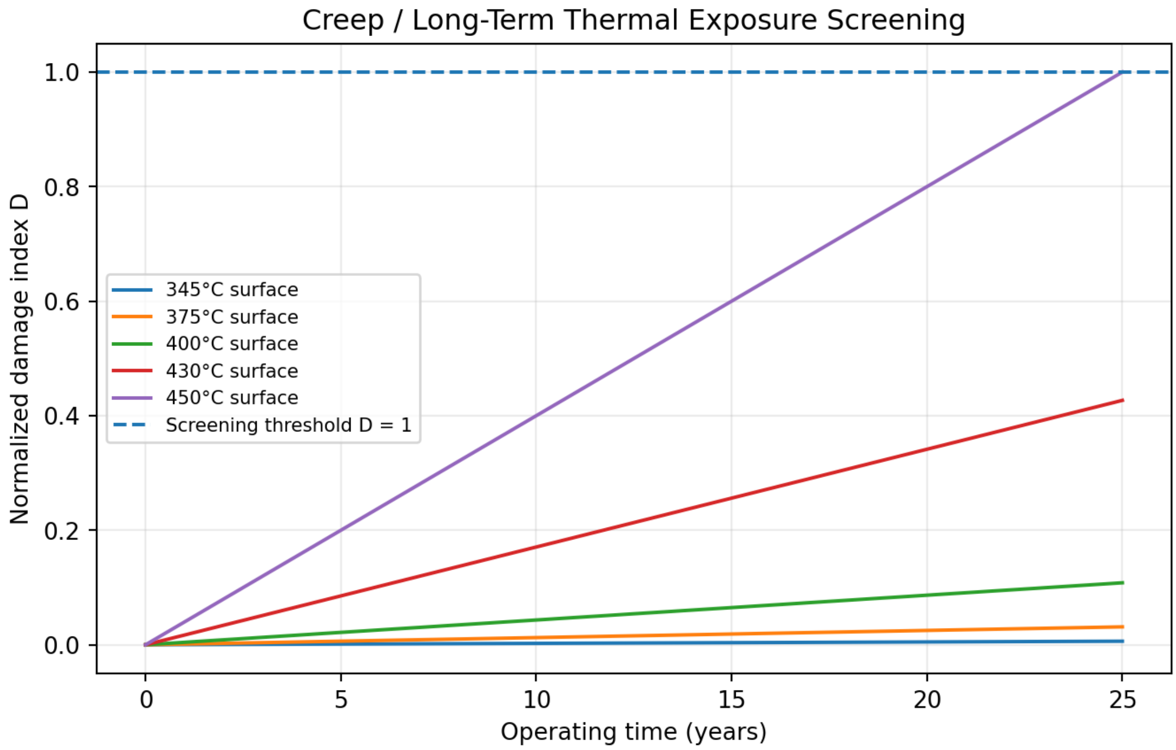

Figure 9. creep_life_damage_index

The normalized damage curves demonstrate the exponential influence of hot-surface temperature over long operating time. The D = 1 line is a screening reference, not a code allowable or predicted failure point.

DIFHEMI therefore reduces the thermal residence time of the fluid at elevated wall temperatures: the continuously moving fluid removes the generated heat before significant localized heat accumulation can develop. This is a fundamental reason for the lower thermal-damage index predicted for induction heating compared with conventional resistance heating.

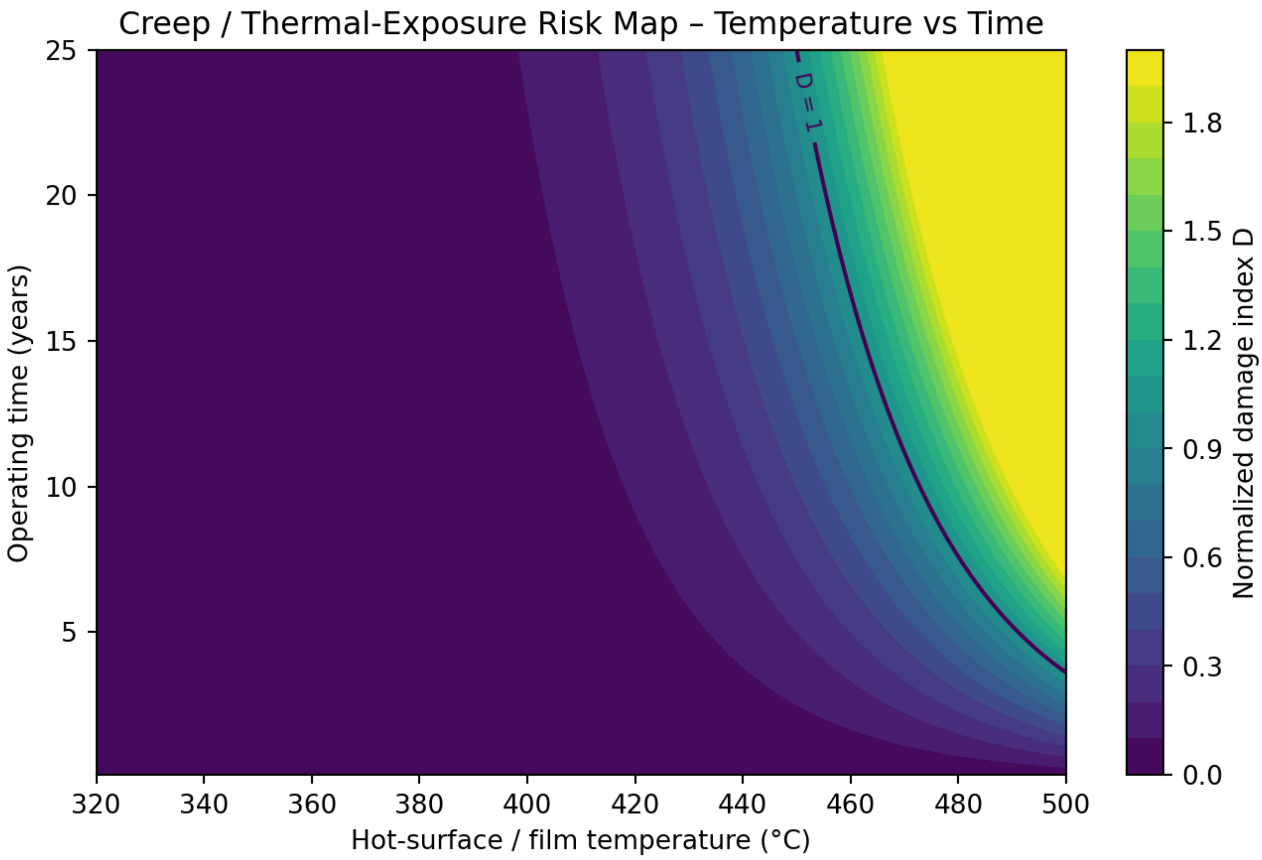

Figure 10. creep_risk_map_temperature_time

The temperature-time map illustrates how increasing local surface temperature rapidly moves the system toward higher long-term thermal-exposure index. It is useful for comparative design screening, not for pressure-equipment life certification.

With DIFHEMI induction heating, the risk of localized hot spots is substantially reduced because heat is generated in a distributed manner along the tube wall and is continuously transferred to the circulating thermal fluid. The combination of controlled wall temperature, continuous fluid movement and short local residence time limits heat accumulation at the fluid–wall interface, thereby reducing the conditions that promote localized overheating, thermal degradation and deposit formation. Fluid–wall interface, thereby reducing the conditions that promote localized overheating, thermal degradation and deposit formation.

In a conventional resistance heater, the heating element must operate at a temperature significantly higher than the bulk fluid temperature. Local heat-flux concentration can therefore expose the adjacent fluid film to substantially higher temperatures. Since thermal degradation follows an exponential Arrhenius-type dependence on temperature, even relatively small increases in local film temperature can result in a disproportionately higher degradation and coking tendency.

15. Engineering Interpretation for Plastics-Industry Thermal Oil

The principal advantage identified by this screening is not simply the nominal bulk-oil temperature. It is the ability to control the local wall/film temperature. With the DIFHEMI assumption used here, a 320°C bulk outlet corresponds to about 345°C at the heating wall. The Arrhenius screening shows why avoiding unnecessary local surface-temperature escalation can have a very large effect on relative thermal-degradation tendency.

- Lower local film temperature reduces the kinetic driving force for cracking, high-boiler formation and deposit formation.
- More distributed heat input reduces local heat-flux concentration.
- Lower radial temperature gradients reduce thermally induced stress and thermal-cycling severity.
- Fast electrical control and low residual heat can reduce post-shutdown heat soak compared with a massive high-temperature resistance element.
- The benefit is especially relevant for continuously operated rolls, calenders, laminators, coating lines, tanks, reactors and centralized thermal-oil systems.

16. What Must Be Checked Before Selecting a DIFHEMI

- Required thermal duty (kW or kcal/h)
- Thermal-oil type and current condition
- Required supply and return temperatures
- Maximum permissible bulk and film temperatures
- Thermal-fluid flow rate
- Operating pressure and expansion-tank arrangement
- Pipe sizes, pump capacity and pressure drop
- Operating schedule and annual running hours
- Existing heater type and efficiency
- Electric power availability and voltage
- Process temperature stability and control requirements
- ATEX, CE, PED, SIL or other applicable safety requirements
- Required redundancy for continuous production
- Insulation condition and distribution losses

+39 339 734 7133
2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
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17. Which Plastics Companies Are the Most Relevant Prospects?

For commercial prospecting, the strongest targets are not necessarily every plastics processor. Priority should be given to companies operating large, continuous processes where thermal oil is already used or where a central thermal-fluid system would be technically appropriate.

- Plastic-film manufacturers: PE, PP, PET and multilayer films
- Flexible-packaging producers
- BOPP and BOPET film plants
- Calendering operations
- Laminating and coating plants
- Polymer and resin producers
- Plastic compounders and masterbatch producers with thermal fluid systems
- Manufacturers operating heated rolls and large process tanks
- Plants running 24/7 or high annual operating hours
- Facilities currently using gas, diesel or other fired thermal-oil heaters

Commercial message

If a plastics plant already has a thermal-oil circuit, the key question is not 'Can DIFHEMI replace an extruder band heater?' but rather 'Can DIFHEMI replace or improve the central source of heat feeding our thermal-oil circuit?'

18. Conclusion

The plastics industry is a particularly interesting field for high-performance thermal-fluid heating because many processes require stable, accurately controlled heat over long operating periods. Electrical resistance heaters remain appropriate for many local machine zones, but central thermal-oil systems create a different opportunity.

DIFHEMI offers a fundamentally different method of generating heat: electromagnetic induction is used to heat the assembly through which the fluid circulates, providing direct and controlled thermal-fluid heating without combustion. For suitable applications, this can combine high efficiency, rapid response, accurate temperature control, reduced maintenance and a compact installation.

The technology can be considered with mineral thermal oils in the lower and medium temperature ranges and with selected synthetic high-temperature fluids for applications extending into the 350–400 °C class. At these higher temperatures, fluid selection, film temperature, flow velocity, pressure, materials and system engineering become increasingly important.

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The final selection should always be based on an application-specific thermal and mechanical design. DIFHEMI is therefore not a one-size-fits-all heater; it is an engineered heating solution designed around the fluid, temperature, flow rate, pressure and process duty of each installation.

Using a representative synthetic thermal fluid and the specified DIFHEMI wall-to-fluid difference of 25°C, the reduced-order analysis indicates a smoother thermal field and materially lower local film temperature than the selected resistance-heater screening cases. With Ea = 180 kJ/mol, the recalculated Arrhenius model predicts a relative degradation/coking-rate index of approximately 5.1× at 375°C, 17.5× at 400°C, 69× at 430°C and 162× at 450°C compared with the 345°C DIFHEMI reference.

The magnitude of these ratios should not be interpreted as measured field coking rates. Their value is comparative: they quantify the strong exponential penalty associated with local overheating and reinforce the importance of controlling wall/film temperature in thermal-oil systems used by the plastics industry.

DIFHEMI — Direct Fluid Heating by Electromagnetic Induction
A high-efficiency approach to generating heat directly in industrial thermal-fluid systems, with particular potential for continuous plastic-processing, film, calendering, laminating and flexible-packaging applications.

19. HISTORY OF DIFHEMI

The origins of DIFHEMI date back to 1983, when Dr. Ing. MSc. Mario Di Giulio pioneered the development of an advanced system for the direct heating of fluids by electromagnetic induction. At a time when conventional electrical resistance heaters, steam systems and combustion-based technologies dominated industrial process heating, this concept introduced a fundamentally different approach: generating heat by electromagnetic induction directly in the metallic heating assembly through which the process fluid circulates.

The development was based on extensive engineering calculations, thermal analysis and practical experimentation. Working within the field of thermal engineering, the pioneers of the technology developed specific calculation methods for the design and sizing of electromagnetic-induction fluid heaters for different operating conditions, fluids, temperatures, pressures and thermal duties. Experimental prototypes were subsequently developed and validated, establishing the foundation of what became known as **DIFHEMI — Direct Fluid Heating by Electromagnetic Induction**.

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One of the distinguishing characteristics of DIFHEMI is its ability to heat a wide range of industrial fluids, in either liquid or gaseous phase. Over the subsequent decades, the technology has been applied to demanding process-heating duties involving thermal oils, petroleum-derived products, aviation fuels such as Jet A-1, natural gas (NG), nitrogen, process gases and other industrial fluids.

This versatility is particularly important when dealing with temperature-sensitive or carbonaceous fluids. Unlike conventional resistance heating, where an electrical element may operate at a temperature considerably higher than the bulk-fluid temperature, DIFHEMI generates heat in the metallic heating assembly itself. Combined with continuous fluid circulation and appropriate thermal design, this allows the wall-to-fluid temperature difference to be closely controlled and reduces the conditions that can promote localized overheating, thermal degradation, fouling and cooking.

The technology is also particularly suitable for demanding industrial environments where safety, reliability and process integrity are essential. DIFHEMI systems can be engineered according to the applicable requirements for hazardous areas, pressure equipment and functional safety, including **ATEX, PED and SIL 2**, as required by the specific project. Applicable pressure-vessel and piping codes are selected according to the equipment configuration and project requirements.

From Energy Efficiency to Decarbonization

Although the development of DIFHEMI began well before the international climate initiatives of the 1990s, its original emphasis on efficient electrical process heating anticipated many of the challenges that industry would subsequently face.

The adoption of the **Kyoto Protocol in 1997** marked an important stage in international efforts to reduce greenhouse-gas emissions. In the following decades, industrial companies faced two increasingly important and simultaneous requirements: improving energy efficiency and competitiveness while reducing dependence on fossil-fuel combustion and lowering the carbon intensity of industrial processes.

In this context, direct electromagnetic-induction fluid heating became increasingly relevant. Where technically and economically appropriate, an electrically powered DIFHEMI system can replace or complement heating systems based on fossil-fuel combustion, steam generation or conventional electrical resistance heating.

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2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
info@aaconsultrade.com
www.aaconsultrade.com

The environmental benefit must nevertheless be evaluated according to the electricity source and the complete process-energy balance. DIFHEMI eliminates **combustion at the heater itself**, while the overall carbon footprint depends principally on the electricity-generation mix and the efficiency of the complete installation.

Energy, Exergy and the DIFHEMI Concept

The thermodynamic significance of DIFHEMI can also be considered from the standpoint of **exergy**.

According to the classical thermodynamic concept developed by Rant and subsequently treated extensively by Kotas, energy is conserved according to the First Law of Thermodynamics; however, not all energy possesses the same capacity to perform useful work.

The total energy of a system can conceptually be separated into:

Energy = Exergy + Anergy

where **exergy** represents the maximum useful work that can theoretically be obtained as a system comes into equilibrium with its reference environment, while **anergy** represents the portion of energy that cannot be converted into useful work under those conditions.

This distinction is particularly relevant to industrial heating. The objective should not simply be to supply a given quantity of energy, but to deliver that energy to the process with the minimum practicable losses and at the temperature and location where it is actually required.

DIFHEMI addresses this objective by converting electrical energy into heat through electromagnetic induction in the heating assembly and transferring this heat directly to the circulating process fluid. By avoiding a conventional combustion stage and, in suitable applications, intermediate heat-transfer stages, the system can reduce unnecessary energy transformations and associated losses.

Properly designed DIFHEMI installations have demonstrated **electrical-to-thermal efficiencies approaching approximately 98% under defined operating conditions**. The exact efficiency, however, must always be established for the particular equipment and operating point, taking into account electrical losses, heat losses to the environment, auxiliaries and the complete system boundary.

DIFHEMI — Direct Fluid Heating by Electromagnetic Induction: more than four decades of development in the direct, controlled and efficient heating of industrial fluids.

Its fundamental principle remains unchanged:

+39 339 734 7133
2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
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Electrical Energy → Electromagnetic Induction → Heated Metallic Surface → Process Fluid

Rather than relying on an excessively hot resistance element, flame or an intermediate heating medium, DIFHEMI is designed to deliver controlled heat directly to the fluid flowing through the heater.

This combination of **high energy efficiency, controlled wall temperature, rapid thermal response, reduced localized overheating, absence of combustion at the heater and applicability to both liquids and gases** makes DIFHEMI particularly relevant to modern industrial requirements for process efficiency, electrification, reliability and decarbonization.

20. Technical Note

Temperature limits and fluid examples in this article are provided for technical orientation. Before specifying a fluid or heater, the latest manufacturer technical data sheet must be consulted. The actual permissible temperature is determined by the specific fluid, bulk temperature, film temperature, system pressure, oxygen exposure, circulation velocity, heat flux and overall system design.

The article incorporates the DIFHEMI/plastics application information previously developed for this project, including the distinction between extruder heating and central thermal-oil heating, the importance of film temperature, and examples of commercial high-temperature thermal fluids.

21. References and Data Basis

- Eastman Therminol VP-1 technical literature: biphenyl/diphenyl oxide eutectic heat-transfer fluid; maximum recommended bulk-use temperature 400°C; manufacturer property tables used as the representative-fluid basis.
- DIFHEMI prior plastics-industry thermal-fluid article: wall-to-fluid ΔT basis and application framing for plastic-film, calendering, laminating and thermal-oil systems.
- Arrhenius screening assumption: apparent activation energy Ea = 180 kJ/mol retained from the preliminary comparison methodology; used only as a comparative engineering index.

+39 339 734 7133
2nd Floor, 164 New Cavendish Street, London W1W 6YT (UK)
info@aaconsultrade.com
www.aaconsultrade.com

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Induction Heater 4 FLUIDS

Eng. Italo Bariola
Sales Department
contact@inductionheater4fluids.com
+39 339 734 7133
+55 11 4056 3350
www.inductionheater4fluids.com

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