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Numerical Investigation of Thermal Propagation in Industrial Mixer Drives - *Assessment of Heat-Transfer Pathways and Gearbox Thermal Mitigation*

Abhishek Varadanam Mekala

Design Engineer, NOV, Dayton, OH, USA.

Abstract

Heat generated by high-temperature processes can propagate axially through mixer shafts and into the seal, low-speed coupling, pedestal, and gearbox region. This study uses steady-state thermal finite-element analysis in SOLIDWORKS to quantify that propagation in two large industrial mixer configurations: a short-pedestal arrangement and a long-pedestal arrangement incorporating a spacer spool. Four configurations were evaluated. Case 1 represents the unmodified short-pedestal mixer, Case 2 adds a NEMA G-7 glass-silicone thermal isolation plate, Case 3 adds seal-lubricant cooling to the short-pedestal configuration, and Case 4 evaluates the unmodified long-pedestal configuration. Process temperatures from 250°C (482°F) to 400°C (752°F) were studied for the short-pedestal baseline and G-7 cases; the seal-cooled short-pedestal and long-pedestal configurations were extended to 500°C (932°F). The low-speed coupling (LSC) temperature was used as the principal drive-side metric and compared with an adopted 93°C (200°F) screening criterion representative of common industrial gearbox thermal limits. The short-pedestal baseline increased from 116.0°C (240.8°F) at a 250°C (482°F) process temperature to 170.3°C (338.5°F) at 400°C (752°F). G-7 isolation produced only a modest reduction, lowering the corresponding temperatures to 113.5°C (236.3°F) and 165.9°C (330.6°F). In contrast, seal-lubricant cooling held the LSC between 37.88°C (100.2°F) and 41.17°C (106.1°F) over 250-500°C (482-932°F). The long-pedestal baseline, without G-7 or seal cooling, maintained the LSC between 44.61°C (112.3°F) and 50.09°C (122.2°F) over the same 250-500°C (482-932°F) range. These results show that the dominant thermal-management mechanisms are localized heat removal near the seal and increased thermal path length/exposed area associated with the long-pedestal geometry, whereas passive G-7 isolation alone provides limited benefit when parallel metallic conduction paths remain.

Keywords: *Industrial Mixer; Finite Element Analysis; Shaft Heat Conduction; Mechanical Seal Cooling; Thermal Management.*

INTRODUCTION

Large top-entry industrial mixers used in elevated-temperature service must maintain reliable mechanical separation between the hot process and temperature-sensitive drive components. The process-facing shaft is an efficient metallic conduction path, and thermal energy can propagate from the vessel through the shaft, seal assembly, low-speed coupling, pedestal structure, and ultimately toward the gearbox. Excessive drive-side temperatures may reduce lubricant life, affect seals and bearings, and narrow the thermal operating margin of the gearbox. Published gearbox guidance commonly places normal or maximum oil-sump limits in the vicinity of 90-100°C (194-212°F); a 93°C (200°F) value is therefore adopted in this study as a conservative screening criterion rather than as a universal gearbox failure temperature [1, 2].

Thermal control in mixer drive assemblies can be approached in three fundamentally different ways. First, a passive low-conductivity interface can be inserted to increase thermal resistance. Second, active circulation through a mechanical-seal lubrication or barrier-fluid system can remove heat close to the shaft/seal region before that heat reaches the drive. Third, the geometry itself can provide thermal attenuation by increasing conductive path length and exposed surface area. The present work evaluates all three effects within a common large-mixer thermal model. The process and seal-fluid domains were represented through effective convective boundary conditions, enabling the investigation to focus on

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conductive heat propagation through the mixer shaft, seal assembly, pedestal, coupling, and drive-side structure.

NEMA G-7 glass-silicone laminate was selected as the passive thermal isolation material, with a plate thickness of 12.7 mm (0.5 in.). G-7 is a rigid fiberglass/silicone thermoset with low thermal conductivity relative to metals and substantial compressive strength, making it a more appropriate conceptual thermal-break material for a bolted load-bearing interface than flexible graphite. Graphite remains an excellent high-temperature sealing material, but its thermal conductivity is comparatively higher and strongly anisotropic; therefore, it is less attractive when the primary objective is thermal isolation rather than sealing. Vendor data for G-7 report flatwise compressive strengths on the order of hundreds of megapascals and continuous-use temperatures near the low-200°C (approximately 392°F) range, depending on grade [3]. Consequently, structural and grade-specific qualification would still be required for production implementation.

Mechanical-seal thermal behavior is also strongly influenced by convection to the fluid surrounding the seal rings. Prior analytical, numerical, and experimental work has shown that seal heat is redistributed by conduction into the rings and by convection to wetted fluid surfaces [5-8]. In the present mixer model, the seal-lubricant system is therefore represented as a localized forced-convection boundary acting on the coolant-wetted seal/shaft-sleeve region rather than on the entire shaft.

The objectives of this study are to (i) quantify the dependence of LSC temperature on process temperature for a short-pedestal large mixer, (ii) determine the incremental benefit of a G-7 thermal isolation plate, (iii) quantify the effect of seal-lubricant cooling, and (iv) determine whether a long-pedestal/spacer-spool geometry can maintain acceptable drive-side temperatures without additional thermal-management hardware.

NUMERICAL MODEL AND BOUNDARY CONDITIONS

Large-Mixer Configurations

Two large-mixer geometries were analyzed. The short-pedestal configuration places the low-speed coupling and drive support relatively close to the process-side seal region. The long-pedestal configuration increases the axial separation and includes a spacer spool. The long-pedestal arrangement was evaluated in its normal configuration only; G-7 isolation and seal cooling were not added because its baseline LSC temperatures remained below the adopted 93°C (200°F) screening criterion throughout the investigated temperature range. The drive length, measured axially from the back face of the mounting flange to the top of the low-speed coupling, was 360 mm for the short-pedestal configuration and 833.26 mm for the long-pedestal configuration with the spacer spool.

In the modeled large-mixer geometry, the axial distance from the mounting flange to the first shaft region directly exposed to the process, where process heat begins to propagate upward through the shaft, was 419.1 mm.

Table 1. Simulation cases and purpose.

Case	Pedestal	Thermal modification	Purpose
1	Short	None	Baseline process-to-drive thermal propagation
2	Short	G-7 thermal isolation plate	Passive thermal resistance at drive-side interface
3	Short	Seal-lubricant cooling	Localized active heat removal near seal/shaft region
4	Long + spacer spool	None	Geometry-driven passive thermal attenuation

Heat-Transfer Model

The study uses steady-state conduction within the solids and prescribed convection boundaries at process-exposed, ambient-exposed, internal-pedestal, and seal-cooling surfaces. The conductive heat flux follows Fourier's law, while convection is represented using Newton's law of cooling:

$$q = -k A (dT/dx)$$

$$q'' = h (T_s - T_\infty)$$

The process temperature was applied both as the prescribed temperature at the process-side shaft cut face and as the bulk temperature for process-facing convection. Process convection was applied exclusively to surfaces in direct contact with the hot process fluid. Heat transfer to the seal, low-speed coupling, and pedestal regions therefore occurred through the modeled solid conduction paths rather than through direct process-fluid exposure. This distinction prevents artificial direct heating of upper drive components.

The primary parametric range was 250-400°C (482-752°F). Cases 3 and 4 were additionally evaluated at 500°C (932°F) to assess thermal performance under a severe high-temperature process condition. This upper condition is consistent with published mechanically stirred thermochemical processes, including mixed-thermoplastic pyrolysis performed in a stirred-tank reactor at 500°C (932°F) [4].

Table 2. Thermal boundary conditions used throughout the simulations.

Boundary	Coefficient h ($W/m^2 \cdot K$)	Bulk/reference temperature	Application
Process-side convection	250	Equal to simulated process temperature	Process-wetted faces inside vessel
External ambient convection	30	313.15 K (40°C/104°F)	Outside faces exposed to plant air / fan-assisted ambient cooling
Internal pedestal convection	10	313.15 K (40°C/104°F)	Weak convection on enclosed pedestal-air surfaces
Seal-lubricant cooling (Case 3)	1000	303.15 K (30°C/86°F)	Coolant-wetted seal and shaft/ sleeve region

The process-side coefficient of 250 $W/m^2 \cdot K$ is treated as an effective boundary parameter and was held constant so that the influence of process temperature and configuration could be isolated. The external value of 30 $W/m^2 \cdot K$ represents moderate air movement around the equipment, while 10 $W/m^2 \cdot K$ represents weaker convection within the enclosed pedestal. The seal-lubrication/cooling circuit was represented by an effective convective heat-transfer coefficient of 1000 $W/m^2 \cdot K$ at a bulk-fluid temperature of 30°C (86°F). This value is consistent with the lower end of coefficients reported in mechanical-seal thermal analyses. A mechanical-seal thermal analysis reported local convective heat-transfer coefficients of approximately 1016-2091 $W/m^2 \cdot K$ on sealing-liquid-exposed ring boundaries for a model with a bulk sealing-liquid temperature of 300 K [9]. The selected value of 1000 $W/m^2 \cdot K$ was therefore adopted as a conservative effective representation of liquid-side heat removal in the seal region. It is not treated as an intrinsic fluid property, since mechanical-seal convection depends on the fluid properties, circulation conditions, rotational motion, and seal-chamber geometry [5, 6].

G-7 Thermal Isolation Plate

Case 2 introduces a 12.7 mm (0.5 in.) thick rigid NEMA G-7 glass-silicone thermal isolation plate at the drive-side interface. The SOLIDWORKS custom material definition used a low thermal conductivity of 0.2256 $W/m \cdot K$. The plate was modeled as a load-bearing thermal break rather than a soft sealing gasket. Bonded thermal contact was used at the intended mating interfaces so that heat must conduct through the G-7 body rather than bypassing it through direct metal-to-metal contact. The principal thermal-resistance mechanism is $R_{th} = L/(kA)$; therefore, low conductivity increases resistance to heat crossing the interface. The production suitability of the joint, including bolt preload, creep, alignment, and grade-specific high-temperature capability, is outside the scope of this thermal-only study.

Seal-Lubricant Cooling Representation

Case 3 represents the mechanical-seal lubrication/cooling system as forced convection acting over the internal wetted region near the seal and shaft sleeve. The seal-cooling boundary was applied over the approximate axial extent of the seal-fluid chamber, representing convective heat removal from the coolant-wetted seal and adjacent rotating surfaces. This is consistent with the physical role of circulating seal fluid, which removes heat from seal components and adjacent wetted rotating surfaces. Prior work on mechanical seals demonstrates that convection to the chamber or flush fluid is a major heat-removal mechanism [5-8].

Output Metric and Thermal Screening Criterion

The primary response variable is the temperature at a consistent probe location on the low-speed coupling adjacent to the gearbox interface. A 93°C (200°F) screening criterion is used for comparison. This threshold is not asserted as a universal maximum coupling temperature; rather, it is a conservative gearbox-side screening value consistent with published industrial reducer guidance that places operating limits in the approximately 90-100°C (194-212°F) range [1, 2]. The actual gearbox oil and bearing temperatures were not explicitly modeled.

RESULTS

Short-Pedestal Baseline (Case 1)

The unmodified short-pedestal mixer exhibited a strong and nearly linear increase in LSC temperature with process temperature. The LSC increased from 116.0°C (240.8°F) at a 250°C (482°F) process temperature to 170.3°C (338.5°F) at 400°C (752°F). Every baseline point exceeded the 93°C (200°F) screening criterion. Linear regression gives a thermal sensitivity of approximately 0.362°C/°C (equivalently 0.362°F/°F) increase in LSC temperature relative to process temperature over the investigated range (R^2 = 1.000). The contour field shows the shaft and lower seal/support region as the principal hot path, with progressive attenuation toward the upper drive structure.

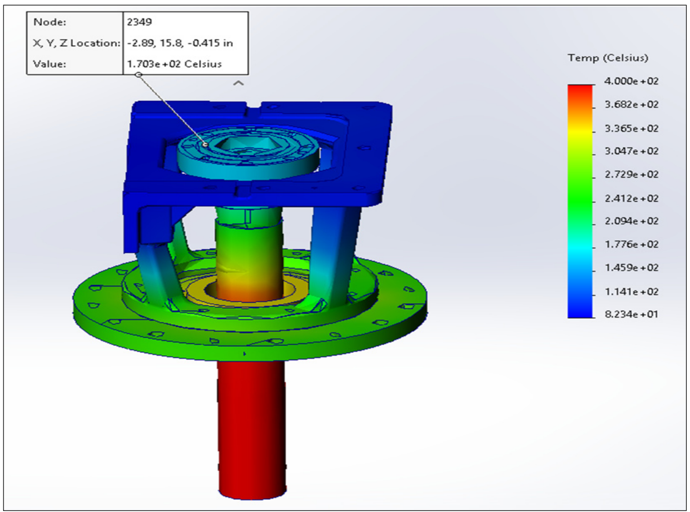

Figure 1. Case 1 short-pedestal baseline at 400°C (752°F) process temperature; LSC temperature = 170.3°C (338.5°F).

Short Pedestal with G-7 Isolation (Case 2)

G-7 isolation reduced the LSC temperature at each process condition, but the reduction was modest. At 250°C (482°F), the LSC decreased from 116.0°C (240.8°F) to 113.5°C (236.3°F), a 2.5°C (4.5°F) reduction. At 400°C (752°F), the reduction increased to 4.4°C (7.9°F), from 170.3°C (338.5°F) to 165.9°C (330.6°F). The G-7 curve remained nearly parallel to the baseline, with a fitted sensitivity of 0.349°C/°C (equivalently 0.349°F/°F). This result indicates that the isolated interface is only one branch of the thermal network. Heat can continue to reach the low-speed coupling through metallic shaft/coupling paths and other parallel conduction routes, limiting the benefit of passive interface isolation alone.

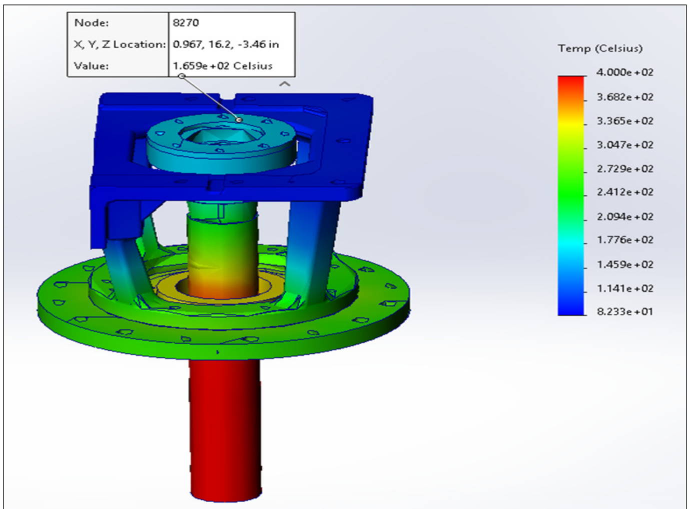

Figure 2. Case 2 short pedestal with G-7 thermal isolation at 400°C (752°F) process temperature; LSC temperature = 165.9°C (330.6°F).

Short Pedestal with Seal-Lubricant Cooling (Case 3)

The seal-lubricant cooling boundary fundamentally changed the thermal response. LSC temperature remained close to the cooling/ambient range despite increasing process temperature: 37.88°C (100.2°F) at 250°C (482°F), 38.53°C (101.4°F) at 300°C (572°F), 39.19°C (102.5°F) at 350°C (662°F), 39.85°C (103.7°F) at 400°C (752°F), and 41.17°C (106.1°F) at 500°C (932°F). Because the LSC remained well below the 93°C (200°F) screening criterion at 400°C (752°F), the 500°C (932°F) simulation was included as an upper severe-condition check using the same literature-supported high-temperature condition described in the heat-transfer model [4]. The fitted temperature sensitivity decreased to approximately 0.0132°C/°C (equivalently 0.0132°F/°F), more than an order of magnitude lower than the baseline response. At 400°C (752°F), seal cooling reduced the LSC temperature by 130.45°C (234.8°F) relative to the short-pedestal baseline. The result indicates that removing heat locally near the seal/shaft region is much more effective than attempting to block heat farther upstream at a passive interface.

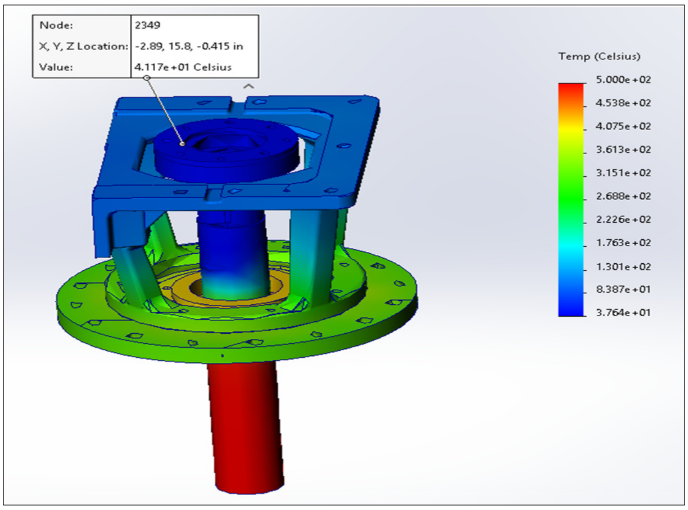

Figure 3. Case 3 short pedestal with seal-lubricant cooling at the 500°C (932°F) upper severe process condition; LSC temperature = 41.17°C (106.1°F).

Long-Pedestal Baseline with Spacer Spool (Case 4)

The unmodified long-pedestal configuration also maintained low drive-side temperatures without G-7 isolation or active seal cooling. The LSC temperature increased only from 44.61°C (112.3°F) at 250°C (482°F) to 50.09°C (122.2°F) at 500°C (932°F), corresponding to a fitted sensitivity of approximately 0.0219°C/°C (equivalently 0.0219°F/°F). As the 400°C (752°F) result remained well below the 93°C (200°F) screening criterion, the long-pedestal baseline was likewise extended to 500°C (932°F) using the same literature-supported severe process condition adopted for Case 3 [4]. At 400°C (752°F), the long-pedestal baseline LSC temperature was 47.89°C (118.2°F), 122.41°C (220.3°F) below the short-pedestal baseline. Because the long-pedestal baseline remained comfortably below the 93°C (200°F) screening criterion at all investigated conditions, additional G-7 and seal-cooling variants were not required for this geometry. The result indicates that increased separation distance, conduction path length, and additional exposed surface area can provide substantial passive thermal attenuation.

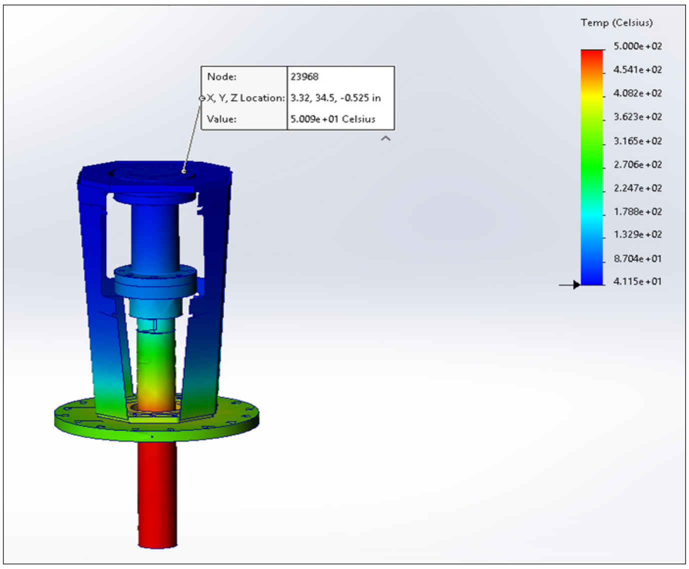

Figure 4. Case 4 long-pedestal baseline at the 500°C (932°F) upper severe process condition; LSC temperature = 50.09°C (122.2°F).

Table 3. Low-speed coupling temperatures from the large-mixer simulations.

Process temperature, °C (°F)	**Case 1 short baseline**	**Case 2 short + G-7**	**Case 3 short + seal cooling**	**Case 4 long baseline**
250 (482)	116.0 (240.8)	113.5 (236.3)	37.88 (100.2)	44.61 (112.3)
300 (572)	134.1 (273.4)	130.9 (267.6)	38.53 (101.4)	45.70 (114.3)
350 (662)	152.2 (306.0)	148.4 (299.1)	39.19 (102.5)	46.80 (116.2)
400 (752)	170.3 (338.5)	165.9 (330.6)	39.85 (103.7)	47.89 (118.2)
500 (932)	—	—	41.17 (106.1)	50.09 (122.2)

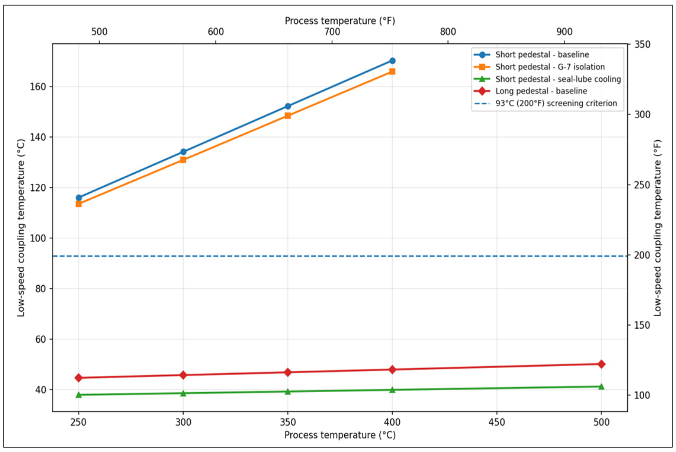

Figure 5. Comparison of LSC temperature versus process temperature for all investigated configurations. The 93°C (200°F) line is the adopted gearbox-side screening criterion.

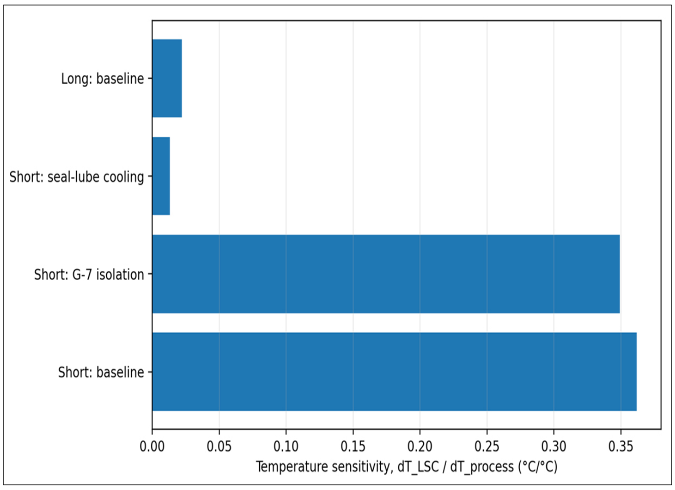

Figure 6. Fitted thermal sensitivity of the LSC to process temperature for the four configurations.

DISCUSSION

Dominant Heat-Transfer Path in the Short Pedestal

The short-pedestal baseline demonstrates that the rotating shaft is an efficient thermal bridge between the process and the drive. The strong 0.362°C/°C (equivalently 0.362°F/°F) LSC sensitivity indicates that a substantial fraction of the process temperature increase is transmitted upward through the metallic assembly. The modest effect of the G-7 plate supports the interpretation that interface conduction is not the only important path. When a low-conductivity plate is inserted at one structural interface, the shaft, coupling hub, fasteners, and other metallic connections can continue to conduct heat in parallel. This explains why a low-k material can be thermally effective locally yet produce only a small change at the LSC system response.

Why G-7 Provides Only Modest Standalone Benefit

At 400°C (752°F), G-7 lowers the LSC temperature by 4.4°C (7.9°F). The increasing difference with process temperature confirms that the plate is adding thermal resistance, but its limited system-level effect shows that passive isolation at a single interface does not control the dominant path. This distinction is important for design interpretation: a thermal isolation plate should not be judged solely by its material conductivity. The entire parallel thermal network must be considered. G-7 remains a useful passive supplement, especially where direct metal-to-metal flange conduction is significant, but the present results do not support using it as the primary thermal-control mechanism for the short-pedestal geometry.

Seal-Lubricant Cooling as a Localized Thermal Intercept

The seal-lubricant system is the dominant mitigation strategy in the short-pedestal configuration. Unlike G-7, which increases resistance after heat has already propagated into the upper assembly, the seal-fluid boundary removes energy close to the shaft/seal region. This creates a localized thermal intercept. Increasing the process temperature from 250°C (482°F) to 500°C (932°F) resulted in only a 3.29°C (5.9°F) increase in LSC temperature, demonstrating strong thermal attenuation at the drive side. Mechanical-seal literature supports the physical basis for this behavior: heat generated or conducted into the seal region is substantially removed by convection to fluid-wetted surfaces [5-8]. The absolute magnitude of the predicted cooling benefit, however, is conditional on the assumed coolant temperature, coefficient, and wetted area. The chosen 1000 $W/m^2 \cdot K$ value should therefore be interpreted as an effective engineering boundary rather than a universal seal coefficient.

Long Pedestal as a Passive Geometric Thermal-Management Strategy

The long-pedestal result is notable because no G-7 plate or seal-cooling boundary was required to keep the LSC below the screening criterion. Increasing the axial distance between the process/seal region and the drive increases conductive path length and provides additional surface area for heat rejection to the surroundings. In thermal-resistance terms, increasing the effective path length L increases R_cond = L/(kA). The additional structure also redistributes heat over a larger volume and surface area. The long pedestal therefore acts as a passive geometric thermal buffer. At 400°C (752°F), its LSC temperature of 47.89°C (118.2°F) is much closer to the actively cooled short-pedestal result of 39.85°C (103.7°F) than to the unmodified short-pedestal result of 170.3°C (338.5°F).

Design Hierarchy Emerging From the Study

The results establish a clear hierarchy for this modeled large-mixer architecture. For the short pedestal, localized seal-lubricant cooling provides the largest reduction in drive-side temperature. Passive G-7 isolation provides only a secondary benefit when used alone. Separately, the long-pedestal/spacer-spool configuration provides strong passive attenuation even without added cooling hardware. The design implication is that thermal management should first address the dominant shaft/seal heat path and overall geometric thermal resistance; low-conductivity interface materials can then be used as supplementary measures where necessary.

CONCLUSIONS

1. The short-pedestal baseline exhibits strong process-to-drive thermal propagation. LSC temperature rises from 116.0°C (240.8°F) at 250°C (482°F) process temperature to 170.3°C (338.5°F) at 400°C (752°F), exceeding the adopted 93°C (200°F) screening criterion throughout the baseline range.
2. A G-7 glass-silicone isolation plate provides measurable but limited standalone improvement. The reduction increases from 2.5°C (4.5°F) at 250°C (482°F) to 4.4°C (7.9°F) at 400°C (752°F), indicating that parallel metallic conduction paths remain dominant.
3. Seal-lubricant cooling is the most effective mitigation method for the short-pedestal geometry. LSC temperature remains between 37.88°C (100.2°F) and 41.17°C (106.1°F) from 250°C (482°F) to 500°C (932°F), demonstrating that localized heat removal near the seal/shaft region can largely decouple the drive temperature from process temperature under the modeled conditions.
4. The long-pedestal/spacer-spool configuration provides strong passive thermal attenuation without G-7 or seal cooling. LSC temperature remains between 44.61°C (112.3°F) and 50.09°C (122.2°F) over 250-500°C (482-932°F) and stays well below the adopted screening threshold.
5. The large-mixer results show that system geometry and the location of heat removal are more influential than adding a low-conductivity plate at a single interface. For the modeled assembly, the most effective strategies are either active thermal interception near the seal or increased drive-to-process separation through long-pedestal geometry.

Future work should include temperature-dependent material properties, thermal radiation, seal-cooling sensitivity to flow rate and coolant temperature, explicit gearbox thermal mass/heat rejection, and a coupled structural assessment of the G-7 bolted interface. Experimental temperature measurements at the seal, LSC, and gearbox interface would provide the strongest validation of the numerical trends. Accordingly, the numerical results should be regarded as engineering predictions pending experimental validation; practical testing is recommended to validate the numerical predictions.

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APPENDIX A. NUMERICAL RESULT SET

The tabulated values below are the probe temperatures used for the comparative analysis and correspond to the contour results generated in SOLIDWORKS.

Table A1. Complete LSC result set used in this manuscript.

Configuration	Process T, °C (°F)	LSC T, °C (°F)	Status vs 93°C (200°F)
Case 1: short baseline	250 (482)	116.0 (240.8)	Above
Case 1: short baseline	300 (572)	134.1 (273.4)	Above
Case 1: short baseline	350 (662)	152.2 (306.0)	Above
Case 1: short baseline	400 (752)	170.3 (338.5)	Above
Case 2: short + G-7	250 (482)	113.5 (236.3)	Above
Case 2: short + G-7	300 (572)	130.9 (267.6)	Above
Case 2: short + G-7	350 (662)	148.4 (299.1)	Above
Case 2: short + G-7	400 (752)	165.9 (330.6)	Above
Case 3: short + seal cooling	250 (482)	37.88 (100.2)	Below
Case 3: short + seal cooling	300 (572)	38.53 (101.4)	Below
Case 3: short + seal cooling	350 (662)	39.19 (102.5)	Below
Case 3: short + seal cooling	400 (752)	39.85 (103.7)	Below
Case 3: short + seal cooling	500 (932)	41.17 (106.1)	Below
Case 4: long baseline	250 (482)	44.61 (112.3)	Below
Case 4: long baseline	300 (572)	45.7 (114.3)	Below
Case 4: long baseline	350 (662)	46.8 (116.2)	Below
Case 4: long baseline	400 (752)	47.89 (118.2)	Below
Case 4: long baseline	500 (932)	50.09 (122.2)	Below