Archimedes / Manufacturing

21x faster gas flow between stacked crucibles.

In a chamber of stacked crucibles, purge gas shot past the gaps between them and left stale gas behind. Archimedes rearranged the gas nozzles so the flow sweeps through the gaps. The result holds in a cold-flow model; a hot check did not confirm it.

ARCHIMEDES TECHNICAL CASE STUDY

How to interpret this report

Results apply only to the stated geometry, operating conditions, numerical models, and verification record.
They are not product certification, safety approval, or a general claim outside the documented scope.
Limitations and adverse findings are retained because they are part of the engineering result.

REPORT ID
crucible-chamber-purge

CANONICAL SOURCE
standardphysics.com/archimedes/crucible-chamber-purge

21x
faster gas flow between the crucibles, in the cold model

0.0035%
of the gap volume left stagnant, down from 5.72%

64
designs simulated on GPUs in 3.7 hours

The ask

Rearrange the gas nozzles, spacing and exhausts so no gap stays stagnant.

Without more than doubling the pressure drop.

What it did

Eight angled nozzles in a ring set the gas swirling.

The swirl pushes gas sideways through all three gaps.

What it found

The centre jet shoots straight past the gaps.

Gas ran up the outer wall and out of the roof, leaving the three gaps between crucibles stale.

What went wrong

At 2,500 °C the advantage disappeared.

A hot check on a related design showed natural convection erasing most of the difference, so this is a cold-flow result, not a hot-process optimum.

For engineers

The full record, unedited.

Interactive comparison `explore the measured results` —

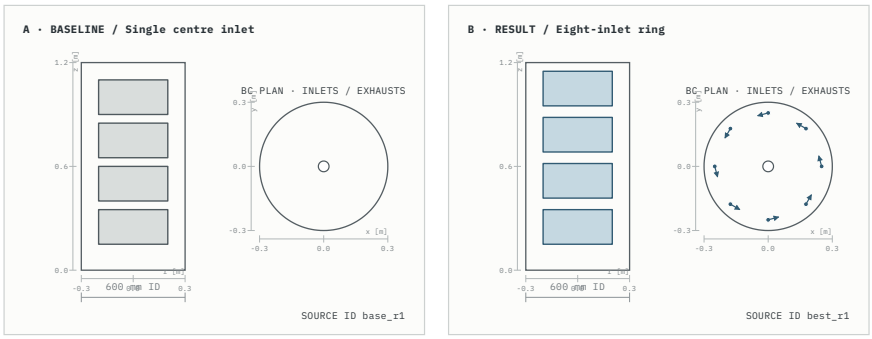
MEASURED COMPARISON

A topology change, not a stronger jet

The plate compares the exact chamber sections, inlet disks, and boundary-vector directions, not interpreted streamlines. The cold-flow candidate improves gap exchange, but the hot check removes the practical velocity advantage.

RECORDED GEOMETRY COMPARISON

FIXED PROJECTION · COMMON SCALE



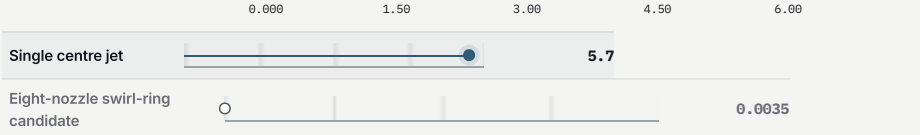
Recorded chamber section and floor BCs. 600 mm ID × 1,200 mm. Geometry is reconstructed from the recorded campaign artifacts.

Geometry only. No inferred streamlines, pressure field, or unrecorded physical detail is shown. Boundary-vector direction is recorded; arrow length is display-only.

A source: jiuyuan_demo/runs/base_r1/design.json · base_r1 · Exact chamber primitives, crucible elevations, inlet disk, and boundary direction vector; arrow length is display-only.
B source: jiuyuan_demo/runs/best_r1/design.json · best_r1 · Exact chamber primitives, crucible elevations, nozzle disks, and boundary direction vectors; arrow lengths are display-only.

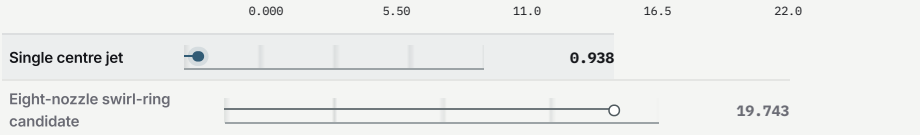
COLD-FLOW STAGNANT GAS SHARE · %

← LOWER IS BETTER



COLD-FLOW MEAN GAP VELOCITY · MM/S

HIGHER IS BETTER →



Separate 2,500 °C check: baseline 17.8 mm/s, Gen 29 18.0 mm/s. Gen 29 is not the selected cold-flow winner, so no hot value is assigned to that design.

BYPASSES THE CRITICAL GAPS

Single centre jet

Axial momentum carries argon up the outer wall channel and leaves the horizontal gaps weakly refreshed.

5.7% stagnant gas, 0.94 mm/s gap velocity

- Gas-age spread 203 s
- Fine-mesh pressure drop 2.330 Pa
- Nozzle Re 2,749

SELECTED COLD-FLOW CANDIDATE

Eight-nozzle swirl-ring candidate

Tangential momentum creates radial pressure gradients that draw purge through all three crucible gaps.

Numerical basis: Full 360 deg 3D GPU-accelerated stabilised finite-element incompressible CFD on an NVIDIA H100, then mean-age scalar transport on the frozen flow. Cold-flow model.

0.0035% stagnant gas, 19.743 mm/s gap velocity

- Gas-age spread 68 s
- Fine-mesh pressure drop 2.448 Pa
- Nozzle Re 1,062

Cold-flow evidence ladder

The 21x gap-velocity ratio is cold, isothermal, and laminar. It is not the hot-process result.

Design	Stagnant share	Gap velocity	Pressure drop	Nozzle Re
Centre jet	5.7%	0.938 mm/s	2.330 Pa	2,749
Eight-nozzle candidate	0.0035%	19.743 mm/s	2.448 Pa	1,062

Separate hot check

The hot solve used Generation 29, not the selected cold candidate, under assumed 1 bar boundaries.

Condition	Baseline	Tested swirl design	Conclusion
Cold selected candidate	0.938 mm/s	19.743 mm/s	Cold ranking only
2,500 C, Gen 29	17.8 mm/s	18.0 mm/s	Advantage disappears
Mesh count	Two levels	Not a GCI study	Ranking is more stable than absolute stagnant share

Applicability

The chamber is an illustrative model. The stagnant threshold uses 5% of mean through-flow velocity, the baseline nozzle is exempt from the laminar-inlet rule, and the hot result does not license a process claim.

References and source records

Cold campaign: 360 degree stabilised finite-element CFD, then mean-age transport on the frozen flow.
Hot-stage record: assumed chamber temperatures and a steady-solver iterate average.

The exact brief as given to the agents

Rearrange the floor argon purge nozzles (1 centre jet or 2-8 ring nozzles, r = 100-280 mm, tilt 0-45 deg, any lean angle, D10-40 mm), optional diffuser plate, crucible gap spacing (30-66.7 mm), and roof exhausts of a D600 x 1,200 mm four-crucible chamber (40 SLPM argon). Minimize inter-crucible gap stagnant fraction S and mean gas-age spread sigma_tau, subject to dp <= 2x baseline and laminar nozzle Re <= 2,300.

ARCHIMEDES
3.67 h autonomous GPU search (64 3D solves)

COMPUTE RECORD
H100 GPU finite-element solver · 74 proposed, 64 completed

Decision log how the agents reasoned, step by step

REASONING TRACE

What changed, and why

The search tuned the prompt-suggested swirl family rather than claiming to invent it. Angular momentum and the resulting radial pressure field move cold gas through the shielded regions.

PROMPT-SUGGESTED SWIRL FAMILY

Tuning the swirl-ring operating point

OBSERVED	INFERRED	CHANGED AND MEASURED
Axial floor jets and diffuser plates still let the purge gas hug the outer cylinder wall, leaving the inter-crucible centres stagnant.	Tilting a ring of 8 floor nozzles 36 deg tangentially (with 15 deg inward lean) imparts angular momentum to the outer annulus; radial pressure gradients then drive Secondary Ekman/vortex inflow right through the crucible gaps.	By the sixth completed solve at roughly 20 minutes, the search reached J = 0.180. Continued tuning reached J = 0.1679 with D10 nozzles, Re = 1,062, and 66.6 mm gaps.

Engineering finding
headline numbers and the mechanism

Faster process-vessel iteration with a visible limit

The cold-flow campaign gives a nozzle and spacing candidate. The 2,500 °C check shows why it cannot yet be treated as a process optimum: natural convection makes the tested swirl design and baseline nearly indistinguishable in mean gap velocity.

0.938 -> 19.743 mm/s

mean inter-crucible gap velocity in the corrected cold-flow model; stagnant fraction fell from 5.72% to 0.0035%

3D GPU CFD · cold-flow model

1.00 -> 0.17

combined flow-uniformity objective (gap dead zones + gas-age spread 203 s -> 68 s); 0.18 on a 1.5x finer 1.63M-tet mesh

Re-solved 2x window + 1.5x mesh

2.448 vs 2.330 Pa

candidate versus baseline pressure drop on the fine mesh; the pressure ordering reverses relative to the search mesh

1.63M-tet refinement · cold flow

Why the mechanism works

The search refined the prompt-suggested swirl family into eight D10 nozzles on a 250 mm ring, tilted 36 deg tangentially and 15 deg inward, with 66.6 mm crucible spacing. In the corrected cold model, angular momentum in the annulus drives secondary radial flow through the three gaps.

What the baseline got wrong

Purge gas fed from a floor centre jet shoots up the annular wall channel and exits the roof, leaving the three horizontal gaps between stacked crucibles stagnant and unevenly aged (203 s age spread).

Full technical record
appendices, families and limits

CAMPAIGN RECORD AND LIMITATIONS

Appendix

The detailed brief, decision record, search families, solver basis, and verification checks are exposed below without tabs or collapsed panels.

Appendix A: Frozen brief and campaign scale

Rearrange the floor argon purge nozzles (1 centre jet or 2-8 ring nozzles, r = 100-280 mm, tilt 0-45 deg, any lean angle, D10-40 mm), optional diffuser plate, crucible gap spacing (30-66.7 mm), and roof exhausts of a D600 x 1,200 mm four-crucible chamber (40 SLPM argon). Minimize inter-crucible gap stagnant fraction S and mean gas-age spread sigma_tau, subject to dp <= 2x baseline and laminar nozzle Re <= 2,300.

Search duration 3.7 h (8 min/design)	**Evaluations** 74 proposed (64 3D CFD)
Compute fleet Up to 2 concurrent H100 slots	**Solver basis** Full 360 deg 3D GPU-accelerated stabilised finite-element incompressible CFD on an NVIDIA H100, then mean-age scalar transport on the frozen flow. Cold-flow model.

Appendix B: Full decision log

01 Minute 00 -> Minute 20 · Prompt-Suggested Swirl Family

Tuning the swirl-ring operating point

OBSERVATION

Axial floor jets and diffuser plates still let the purge gas hug the outer cylinder wall, leaving the inter-crucible centres stagnant.

REASONING

Tilting a ring of 8 floor nozzles 36 deg tangentially (with 15 deg inward lean) imparts angular momentum to the outer annulus; radial pressure gradients then drive Secondary Ekman/vortex inflow right through the crucible gaps.

ACTION AND RESULT

By the sixth completed solve at roughly 20 minutes, the search reached J = 0.180. Continued tuning reached J = 0.1679 with D10 nozzles, Re = 1,062, and 66.6 mm gaps.

Appendix C: Search families

Discrete nozzle, diffuser, and exhaust layouts. These are distinct programs or engineering configurations, not cosmetic renders.

- 8 x D10 tangential swirl ring (r = 250-255 mm, 36 deg tilt, 15 deg inward lean, 66.6 mm gaps · selected cold-flow candidate)
- Swirl ring + perforated diffuser plate variants
- Multi-exhaust roof ring configurations
- Baseline single D25 axial centre jet (50 mm gaps)

Appendix D: Numerical basis and verification

Full 360 deg 3D GPU-accelerated stabilised finite-element incompressible CFD on an NVIDIA H100, then mean-age scalar transport on the frozen flow. Cold-flow model.

- A 2x longer averaging window kept the top two cold-flow candidates near J = 0.168 and 0.169; the 1.63M-tet rerun gave J = 0.18.
- The fine mesh reverses the pressure-drop ordering: 2.448 Pa for the candidate versus 2.330 Pa for the baseline.

The 2,500 °C hot check used Gen 29 rather than the selected cold-flow candidate. Natural convection erased the cold ranking: 18.0 versus 17.8 mm/s mean gap velocity. Radiation, buoyancy, hot properties, and crucible outgassing remain outside the search model.

Appendix E: Reported outcomes and limits

0.938 -> 19.743 mm/s mean inter-crucible gap velocity in the corrected cold-flow model; stagnant fraction fell from 5.72% to 0.0035% Basis: 3D GPU CFD · cold-flow model.	**1.00 -> 0.17** combined flow-uniformity objective (gap dead zones + gas-age spread 203 s -> 68 s); 0.18 on a 1.5x finer 1.63M-tet mesh Basis: Re-solved 2x window + 1.5x mesh.
2.448 vs 2.330 Pa candidate versus baseline pressure drop on the fine mesh; the pressure ordering reverses relative to the search mesh Basis: 1.63M-tet refinement · cold flow.	

Explicit limitations

- The hot check used Gen 29, not the selected cold-flow candidate.
- At 2,500 °C, mean gap velocity is 18.0 versus 17.8 mm/s, so the cold ranking does not survive.
- Radiation, buoyancy, hot properties, and crucible outgassing were outside the search evaluator.

Recorded Archimedes run: 3.67 h autonomous GPU search (64 3D solves). Compute record: H100 GPU finite-element solver · 74 proposed, 64 completed.