Pathways for a More Efficient Water Energy Nexus

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Introduction

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- Short- and Medium-Term Solutions to the Water-Energy Nexus
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- SNL's Approach and Examples:
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  - ✓ State-of-the-Art Experiments
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    - ❖ Swirl Surfaces
    - ❖ Compact Heat Exchangers (CHEs)
- Path Forward
- Conclusion

Motivation

- We are faced with a difficult challenge as a result of diminishing natural resources, a more fragile environment, and an increasing population.
  - ✓ Cities with limited water supplies cannot sustain water-based power systems.
  - ✓ Evaporative water loss at power-generating sites is significant.
    - ❖ Current water cycles require 650 to 850 gallons of water per MWh of generated electricity.
    - ❖ 80,000,000 gallons of water *per day* is lost at Palo Verde nuclear reactors.
- Clearly, this trend is unsustainable for a growing population and diminishing resources.
- It is therefore crucial that advanced technologies be developed, while reducing environmental impact.

Motivation

- At Sandia National Laboratories (SNL), some our energy and water goals are to
  - ✓ Develop new, innovative next-generation power sources,
  - ✓ Reduce the water-consumption footprint required for power production,
  - ✓ Increase the thermal efficiency of power-production components,
  - ✓ Enhance water-condensation techniques to recapture valuable resources.
    - ❖ Plants currently using water-cooling can be modified to recapture a significant fraction of the water vapor via condensation.
- To that effect, we are
  - ✓ Advancing waterless power production for nuclear and non-nuclear systems (e.g., sCO2 secondary loops).
  - ✓ Designing engineered heat transfer and turbulence surfaces (e.g., fractal, dimple, and swirl),
  - ✓ Developing advanced nuclear concepts (miniature and small modular reactors; fusion Z-Pinch).

Short- and Medium-Term Solutions to the Water-Energy Nexus

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<u>Short Term:</u>

- Many power systems in use today were designed by very smart people using slide rules and calculators!
  - ✓ Thus, increased thermal efficiency of current power systems is a certainty using *supercomputers, modern theoretical advances, and state-of-the art experimental technologies.*
- Incorporate new sub-systems onto existing power plants to reduce waste.
  - ✓ Condense cooling tower water vapor.
- Expedite the *application* of proven:
  - ✓ modern computational methods,
  - ✓ material advances,
  - ✓ engineered surfaces,
  - ✓ advanced heat transfer components.
- We don't need to know a system's behavior to the n^{th} degree—*it's time to build!*
  - ✓ If our '60s society were as risk-averse as we are now, we would still be preparing to some day fly to the moon.

Short- and Medium-Term Solutions to the Water-Energy Nexus

<u>Medium-Term:</u>

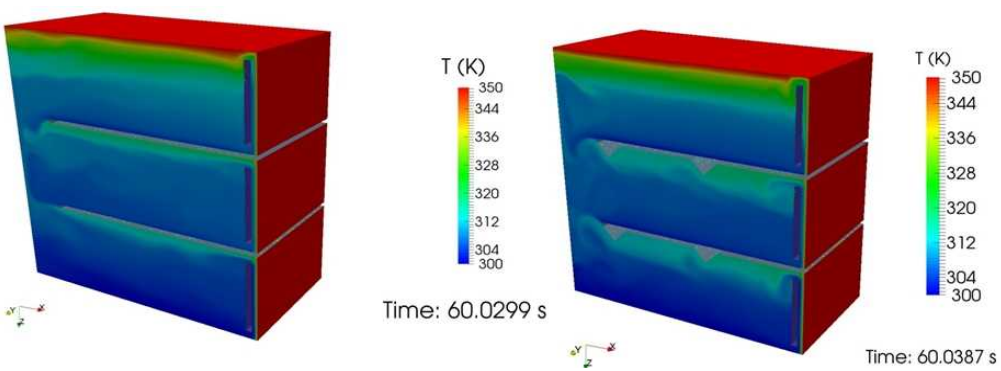
- Expedite the research for next-generation power systems using measurable progress metrics:
  - ✓ Increased thermal efficiency at a *proven, competitive cost*.
  - ✓ Reduced natural resources consumption.
  - ✓ Decreased harmful impact to the environment, when it makes environmental sense.
- Next-generation power systems need to be fully vetted and validated within a timeframe and risk level that financial partners will support.
  - ✓ Aim for cost-effectiveness based on great engineering, not subsidies!
- Recycle natural sources.
- Development of *next-generation engineering tools*:
  - ✓ More advanced computational methods and supercomputers.
  - ✓ Stronger materials for use in high-temperature systems at low cost.
  - ✓ More advanced engineered surfaces with specialized behaviors.

Short- and Medium-Term Solutions to the Water-Energy Nexus

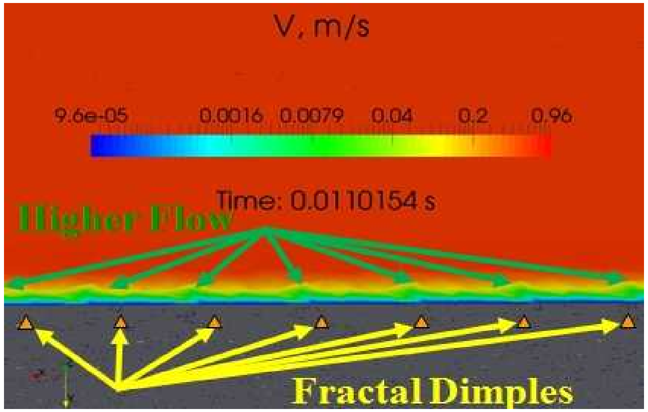
- The next steps for the water-energy nexus are not trivial, but they can most certainly be empowered through
  - ✓ Computational dynamics
  - ✓ State-of-the art validation experiments
  - ✓ Recent metallurgical and engineered-surfaces advances
  - ✓ Collaboration with industrial and financial partners
  - ✓ Regulations that are less risk averse and promote business venture

Example: Fractal and Dimple Surfaces

- Challenge: design an inexpensive, passive, water tank for collection of solar heat (modular solar water tank—MSWT).
- Tools:
  - ✓ Computational fluid dynamics (CFD).
  - ✓ Recent advances in fractal and dimple surfaces.
  - ✓ Particle image velocimetry (PIV).
- Results:
  - ✓ Used CFD/PIV to design MSWT that harvests $575.10/yr. of solar heat.
  - ✓ Total cost to build device: $1,514.41.
  - ✓ Break-even point: 2.6 years.



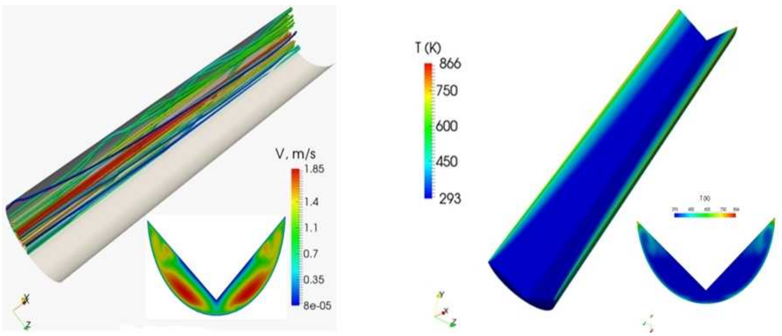
Heat transfer improvement using fins with Sierpinski fractals. Note: this is NOT the final MSWT design.



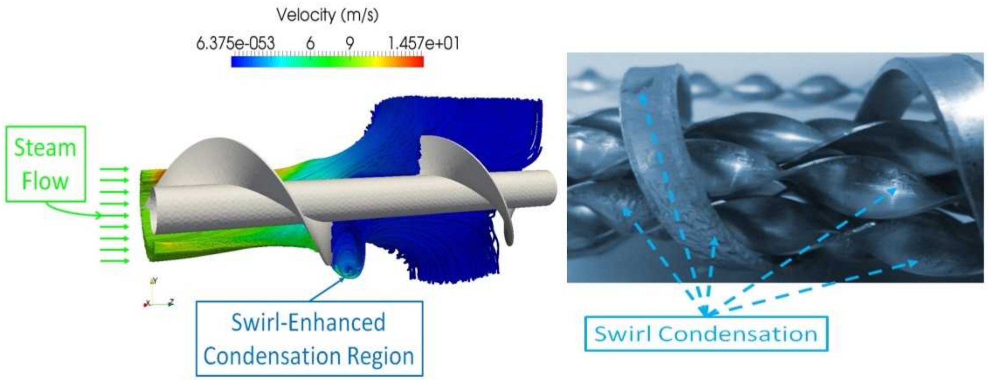
CFD simulation showing higher flow near dimpled wall.

Example: Swirl Surfaces

- Challenge: use passive surfaces to increase condensation; increase thermal efficiency of power systems.
- Tools:
  - ✓ CFD.
  - ✓ Recent advances in swirl.
- Results:
  - ✓ Designed innovative surface geometries that selectively and passively use momentum to increase water condensation and improve heat transfer.
  - ✓ 50% more condensation vs. conventional surfaces.
  - ✓ Validated for arid regions.
  - ✓ Working to obtain USDA grant to refine the technology to enable *self-irrigation* in arid areas and decrease fertilizer use.



Formation of swirl pattern in a toroidal region to selectively transfer heat.



CFD calculation/validation experiment with increased condensation in swirl vanes.

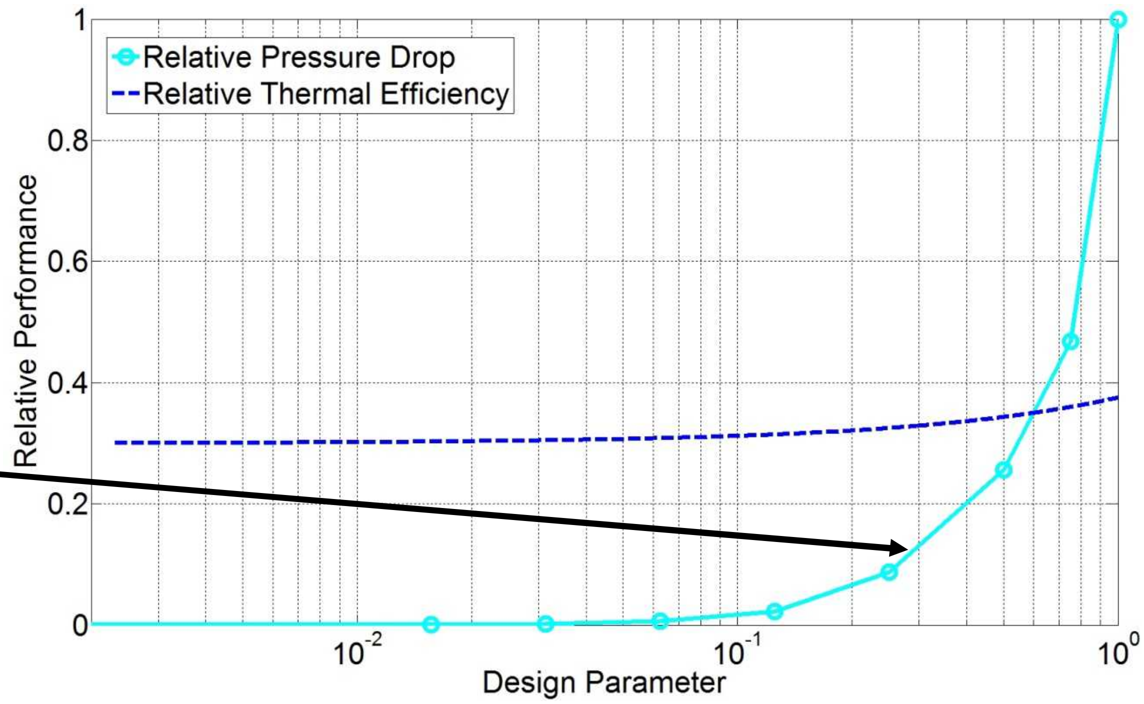
Example: Compact Heat Exchangers (CHEs)

- Challenge:
  - ✓ Increase CHE thermal efficiency while reducing pressure drop.
  - ✓ Provide engineering basis for CHE applicability/scaling to any desired system.
- Tools:
  - ✓ CFD
  - ✓ Recent advances in swirl, fractal, and dimpled surfaces.
  - ✓ PIV
- Results:
  - ✓ Our research shows how to design, optimize, and scale our CHE for any given particular application based on
    - ❖ Operating fluid properties
    - ❖ CHE geometry
  - ✓ The CHE design is currently being validated through PIV.
  - ✓ In the process of submitting a Technical Advance.

Example: Compact Heat Exchangers (CHEs)

- Results (continued):
  - ✓ CFD simulations indicate superb, highly-desirable system performance:
    - ❖ Significantly-reduced pressure drop.
    - ❖ Excellent heat transfer.
    - ❖ Point is reached where further thermal efficiency gains are offset by an excessive pressure drop.

CHE reaches point where additional design parameter changes result in a small thermal efficiency increase at the expense of an excessive pressure drop.



Path Forward

- Computational dynamics is not just "eye candy", but a powerful predictor of system/design behavior and a resource for profitable ventures.
- State-of-the-art PIV validates and provides further design improvements.
- We need to design environmentally-benign power-production equipment:
  - ✓ Cost effective.
  - ✓ Uses little or no water.
  - ✓ Reduced natural resource consumption.
- Government/labs/universities: need to seek emergent technologies with a strong potential for significant short- and medium-term return.
  - ✓ *Industrial collaboration, scientific advances, and profit will fuel the water-energy nexus thereafter.*

Summary/Conclusion

- Recent advances at SNL confirm and extend power-production technology that is critical for the water-energy nexus.
- The combination of CFD- and PIV-informed design provides cost-effective, highly efficient
  - ✓ Upgrades for current systems.
  - ✓ Next-generation power production systems.
- By increasing a surface's ability to radiate and convect more heat under natural circulation, smaller quantities of water are required for power production.
- Engineered surfaces will enable power production in arid areas and those with minimal natural resources.
- Engineered surfaces can significantly improve the performance of key power-production equipment, including CHEs.
- Larger water-condensation rates are achievable through the use of swirl.

Summary/Conclusion

- Certainly, the pathways for a more efficient water-energy nexus will be led through diverse approaches and technologies, including
  - ✓ Computational tools (e.g., CFD, coupled multi-physics),
  - ✓ Advanced materials (e.g., high temperature, composites, ceramics)
  - ✓ Engineered surfaces (e.g., nano, dimpling, fractals, swirl)
  - ✓ Manufacturing (e.g., 3D printing)
  - ✓ State-of-the-art experiments (e.g., PIV),
  - ✓ Less risk aversion and control,
  - ✓ Good business environment.
- The above form the crucial building blocks for the commercialization of next-generation power-production systems.