COMSOL
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MODELING A COMBINED PHOTOVOLTAIC-THERMAL SOLAR PANEL

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Many Factors are Influencing Development of Green Energy Solutions

- Global warming
- Rising fuel prices
- Worldwide conflict
- Increased environmental awareness
- National and international economies

usgreentechnology.com

"One of the main impediments to renewable energy has been that it's expensive. It hasn't been cost competitive with fossil fuels. Well, that's changing."

—Vipin Gupta, a systems engineer and a principal member of the technical staff at Sandia National Laboratories

phoenixfocus.com

"When we talk about green jobs, the possibilities are limitless."

—Joel Makower, chairman and executive editor of GreenBiz Group

phoenixfocus.com

Numerous Green Energy Solutions Already Exist and are Continuously Being Optimized

- Wind energy
  - Wind turbines and wind farms
- Geothermal energy
  - Geothermal heating and cooling systems
- Hydroelectric energy
  - Dams
- Tidal energy
  - Underwater turbines
  - Kinetic motion systems
- Solar energy
  - Photovoltaic solar panels
  - Thermal solar panels
  - Photovoltaic – thermal solar panels

Utilityexchange.co.uk

Inhabitat.com

PV/T Solar Panels are More Efficient than Conventional Solar Panels

- Conventional photovoltaic panels produce electricity only
  - PV panels have low solar-to-electrical energy efficiencies
  - Solar energy not created into electricity is converted to heat
  - As PV panel temperature increases, the electrical efficiency decreases
- PV/T solar panels produce electricity while capturing lost solar energy (heat)
  - Cooling fluid flows through heat exchanger attached to PV panel
  - Cools panel, increasing electrical efficiency
  - Fluid can be used for alternative application

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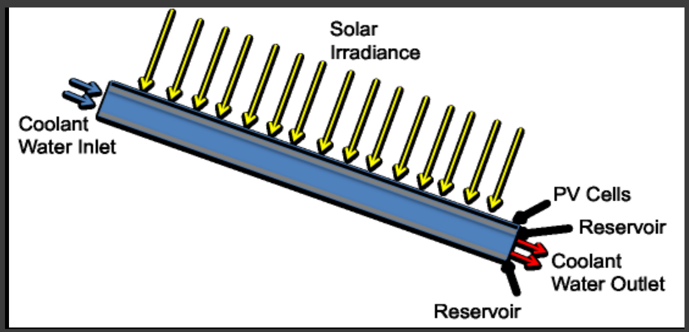
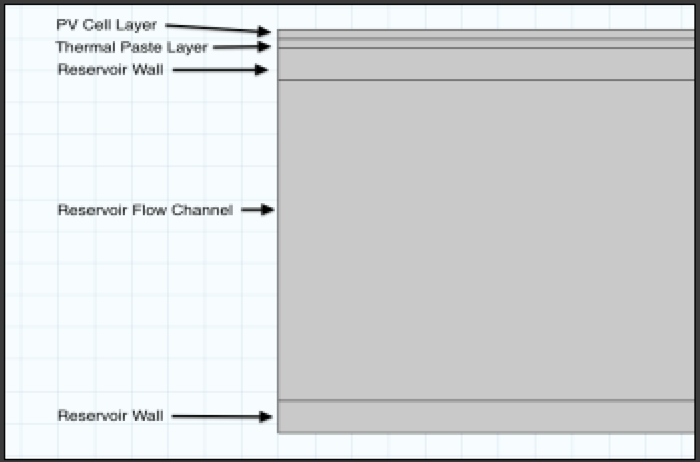
Browndailyherald.com

An Analysis of a Novel PV/T Solar Panel was Performed Using COMSOL





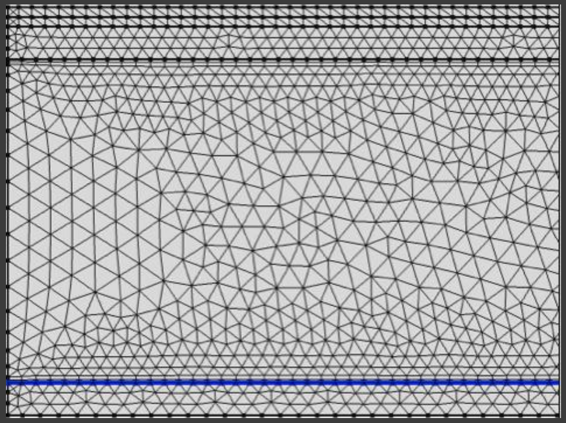
- PV/T panel consists of a rectangular reservoir mounted to the back of a conventional PV panel
- PV cell properties
  - 30.5 cm X 30.5 cm X 0.27 mm
  - Commercial grade monocrystalline PV cells (η_{Tref} = 13%, β_{ref} = 0.54%)
- Silicone thermal paste layer (~0.3 mm uniform thickness) to assist in conductive heat transfer between PV cells and reservoir
- Aluminum reservoir walls (uniform thickness of 1 mm)
- Material properties were included in COMSOL material library

An Analysis of a Novel PV/T Solar Panel was Performed Using COMSOL (cont.)

- Twelve test cases were analyzed
  - Three different reservoir thicknesses
    - 0.015 m
    - 0.010 m
    - 0.005 m
  - Four different water flow velocities
    - 0.0002 m/s
    - 0.001 m/s
    - 0.005 m/s
    - 0.01 m/s

  Re < 2300
  Laminar Flow

- Constants
  - Water inlet temperature: 298 K
  - Solar irradiance: 1000 W/m^2
  - Ambient temperature: 298 K
  - Wind Speed: 1 m/s
- Assumptions
  - All solar irradiance that is not converted to electricity develops into heat
  - No dust or other agent on surface will affect solar energy absorptivity
  - No EVA encapsulating layer to decrease solar energy absorptivity
  - All evaluations considered to be steady-state



Normal mesh setting was used in Physics Controlled Mesh Sequence Setting (~ 15,500 elements)

An Analysis of a Novel PV/T Solar Panel was Performed Using COMSOL (cont.)

- The "Conjugate Heat Transfer" physics module in COMSOL was used to evaluate the PV/T thermal model
  - Conduction through PV cell surface to reservoir solved by conduction equation

$$\nabla \cdot (k \nabla T) = 0$$

  - Forced convection on top and bottom of PV/T panel solved by convection equation

$$q_{conv} = -h_{c,forced} A \left(T_{pv} - T_{amb} \right)$$

  - Forced convection through the reservoir solved by conduction convection equation

$$\rho C_p u \cdot \nabla T = \nabla \cdot \left(k \nabla T \right)$$

  - Continuum and momentum equations were solved for flow

$$\nabla \cdot (\rho u) = 0$$

$$\rho u \cdot \nabla u = -\nabla p + \nabla \cdot \left(\mu \left(\nabla u + (\nabla u)^T \right) \right)$$

  - Long-wave radiation heat loss from the PV/T panel was also solved

$$q_{lw} = \varepsilon \cdot \sigma \cdot \left(T_{pv}^4 - T_{amb}^4 \right)$$

An Analysis of a Novel PV/T Solar Panel was Performed Using COMSOL (cont.)

- User created variables were evaluated in COMSOL at each simulation time-step

- The electrical efficiency as a function of:
  - Ambient temperature
  - PV cell temperature
  - Thermal coefficient of PV cell
  - PV cell reference efficiency

$$\eta_{pv} = \eta_{T_{ref}} \left\lfloor 1 - \beta_{ref}\left(T_{pv} - T_{ref}\right) \right\rfloor$$

- The amount of solar energy that was developed into heat as a function of:
  - PV/T electrical efficiency
  - Solar irradiance

$$q''_{heat} = q''_{rad} \cdot \left(1 - \eta_{pv}\right)$$

- The thermal efficiency as a function of:
  - Heat energy carried away by water
  - Total energy into the PV/T panel

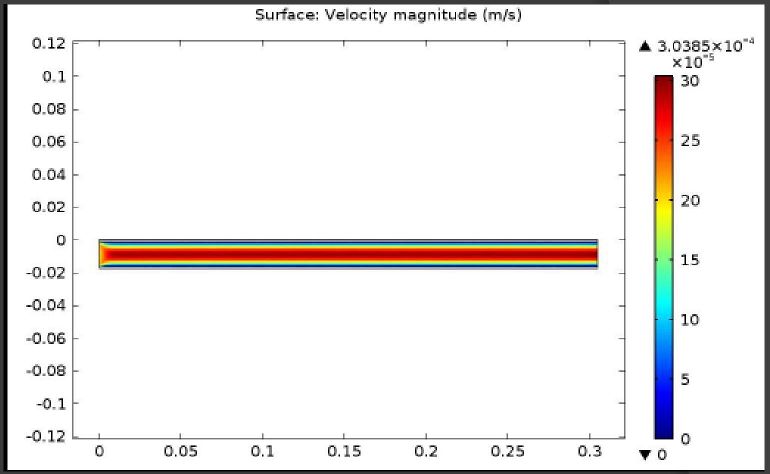
$$\eta_{th} = \frac{E_{water}}{E_{in}}$$

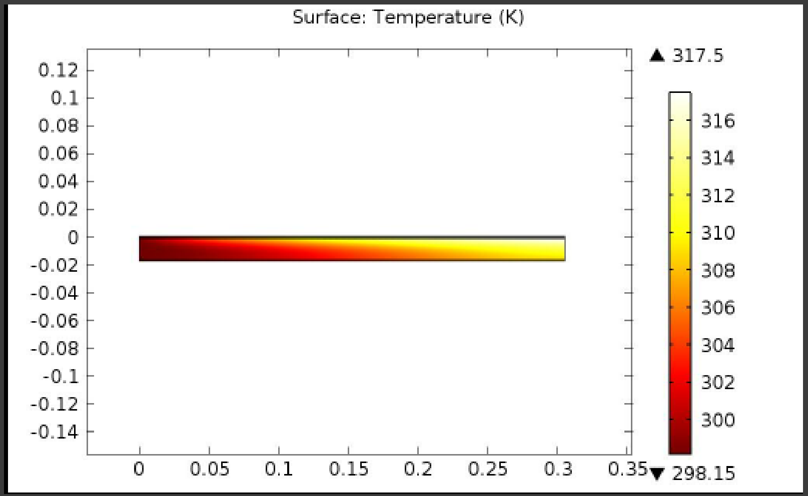
- The total efficiency of the PV/T panel as a function of:
  - Energy created into electrical energy
  - Heat carried away by the coolant water
  - Total energy into the PV/T system

$$\eta_{tot} = \frac{\left(E_{water} + E_{pv}\right)}{E_{in}}$$

An Analysis of a Novel PV/T Solar Panel was Performed Using COMSOL (cont.)

- 2-D laminar flow profiles were plotted to show flow characteristics

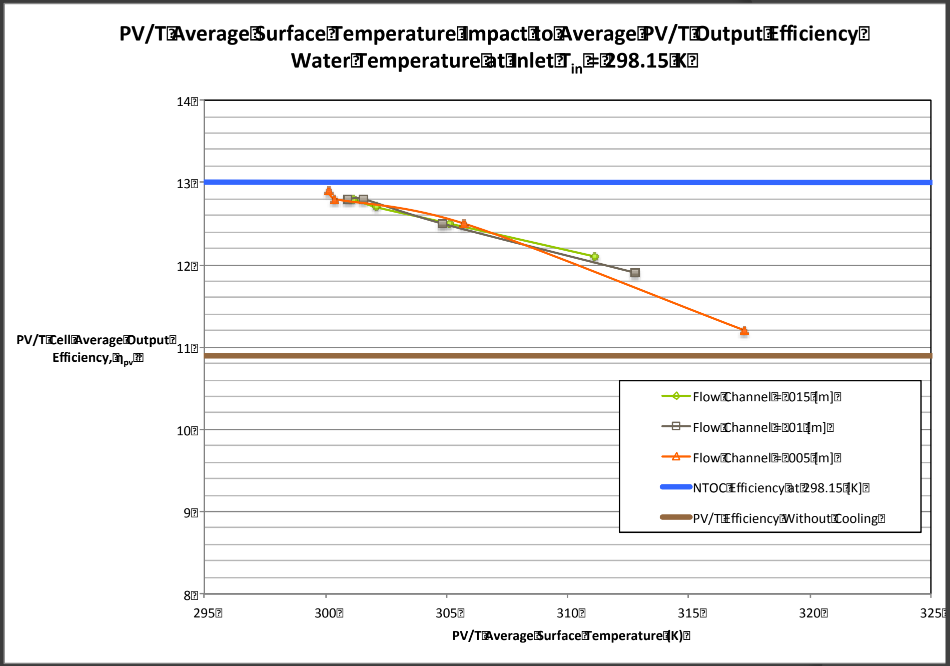


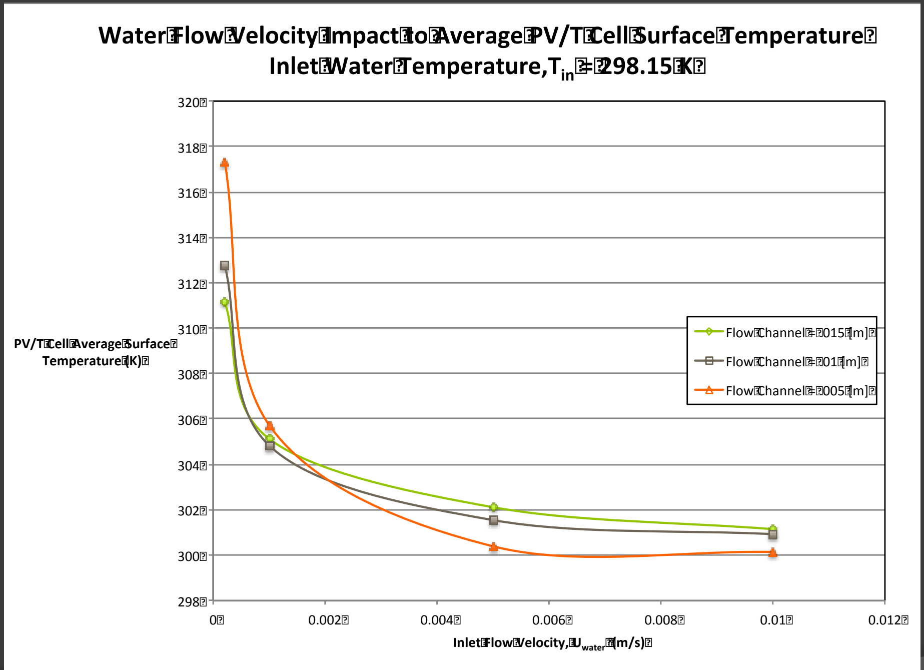


Flow Thk. = 0.015 m
Flow Vel. = 0.0002 m/s

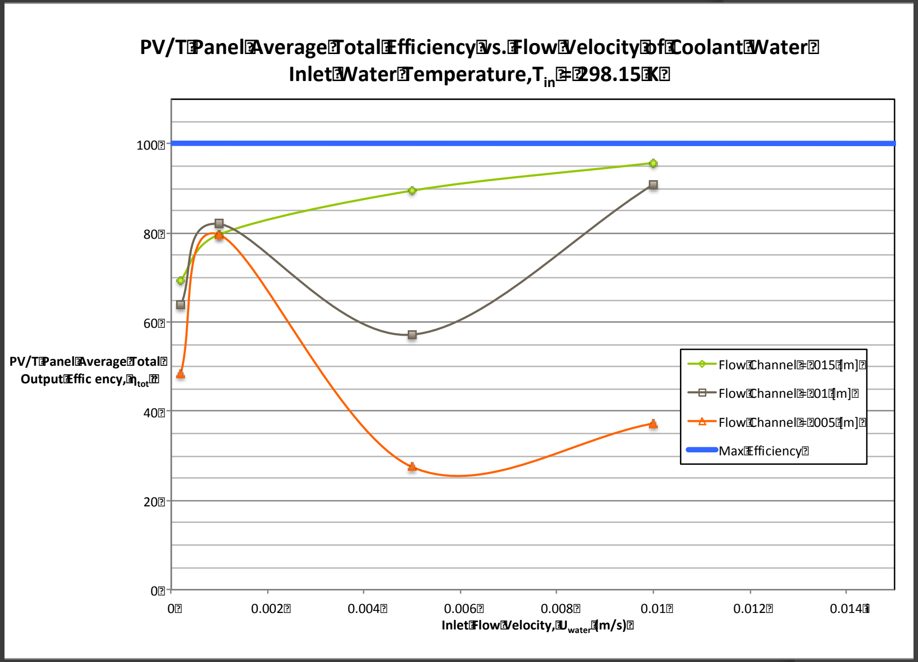
- 2D surface plots of temperature were created to show heat distribution profiles in the PV/T solar panel

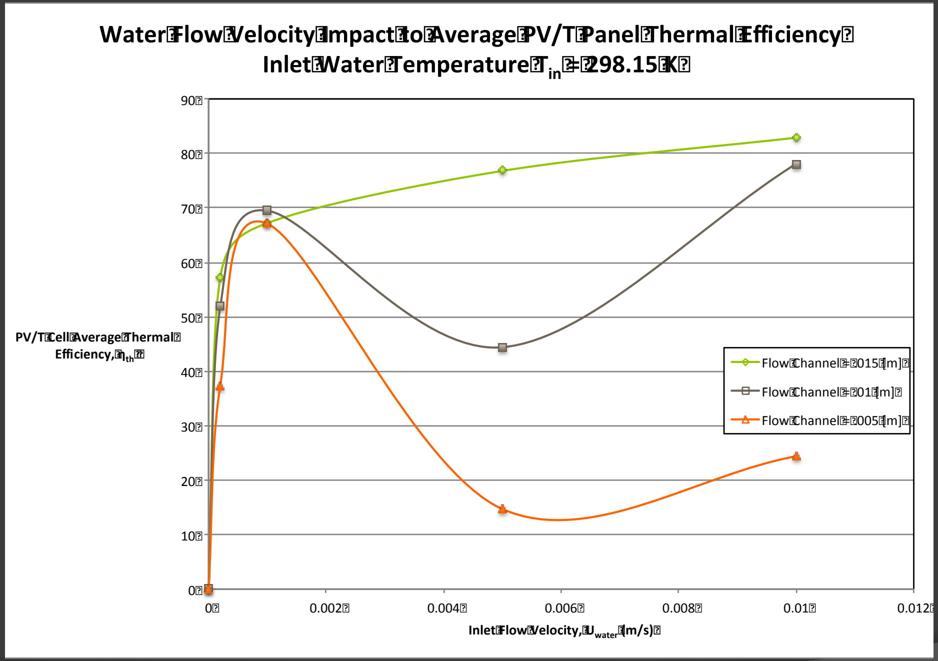
Higher Flow Velocity and Smaller Flow Thickness Yield Lower PV/T Surface Temperatures and Improved Electrical Efficiency





Large Flow Thicknesses and High Flow Velocities Resulted in Highest PV/T Panel Efficiencies





Conclusions

- PV/T system lineups with the highest recorded total efficiencies may not be the most practical
  - Very low temperature change from inlet to outlet of PV/T panel provides no real use for practical applications
  - Higher coolant water flow rates will require bigger pumps for large arrays, negating electrical efficiency gains
- Total efficiencies unrealistic due to simplified evaluation assumptions
  - Conservative to assume that all lost solar energy is developed into heat
  - Not all solar energy is of correct wavelength for a given PV cell to absorb
  - An EVA encapsulating layer on PV cell is typically applied to prevent damage, which contributes to reduction in absorptivity
  - Different ambient and water inlet temperatures will affect efficiency
- Future work
  - Test different ambient conditions
  - Investigate alternative cooling fluids and reservoir designs