Geothermal Technologies Program 2010 Peer Review

Air-Cooled Condensers in Next-Generation Conversion Systems

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Track: Specialized Materials and Fluids and Power Plants

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Project Overview

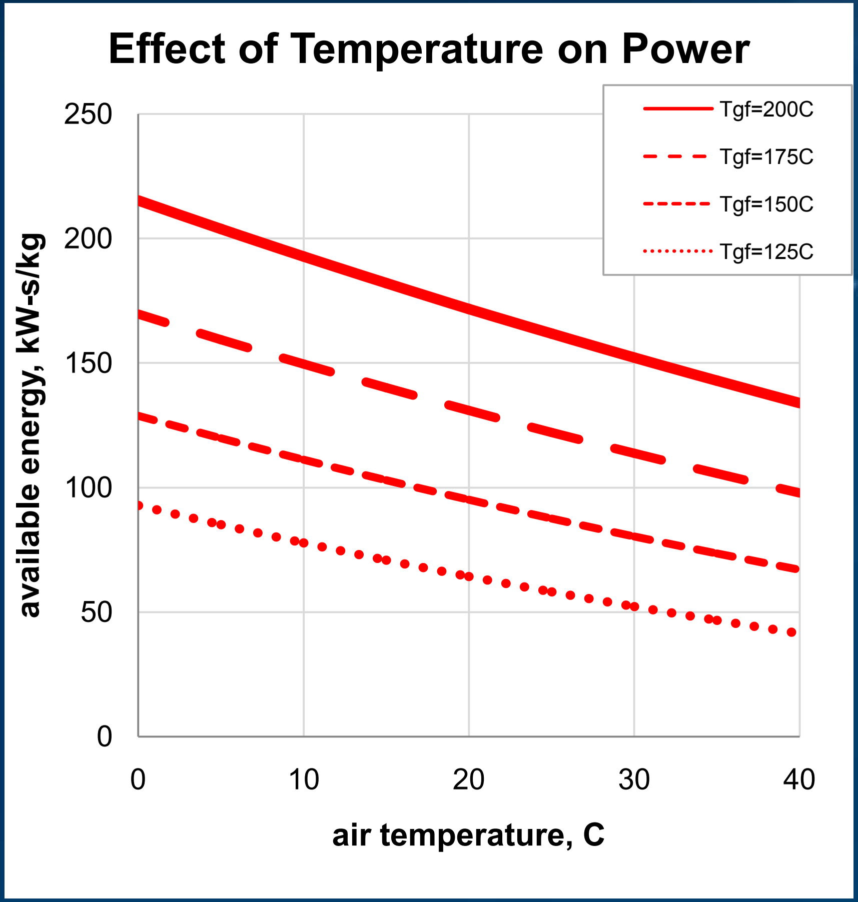
- **Timeline:**
  - Start Date: October 2009
  - End Date: September 2011
  - ~15% Complete
- **Budget:**
  - FY2010: $375K
  - FY2011: $435K
- **Barriers:**

  The impact of air-cooling on plant performance and the costs of air-cooled condensers are barriers that will impact DOE's goal to develop low-cost conversion systems that are more efficient for both EGS and low-temperature resources.
- **Partners:** None

Relevance/Impact of Research:

- The overlying objective is to reduce the costs associated with the generation of electrical power from air-cooled binary plants
- Premise for this work: No water is available for evaporative cooling
- Issues with Air-Cooling
  - Amount of heat rejected – up to ~90% of heat added is rejected
  - Cost - 30 to 45% of Capital Equipment Cost (EPRI Next Generation Geothermal Power Plant study)
  - Fan power - up to 10% of generator output
  - Sensitivity to temperature change: @150°C ~1.4% Δavailable energy per °C Δair temperature

Relevance/Impact of Research:



- **Plant performance: function of source and sink temperatures, and conversion efficiency**
- **Conversion efficiency degrades with deviation from design temperatures**
- **Focus is on**
  - **Minimizing the effect of temperature changes on conversion efficiency**
  - **Increasing conversion efficiency by using mixed working fluids**

Scientific/Technical Approach

- Assume no consumptive use of water
- Two resource scenarios (200° and 150°C); two representative locations (Grand Junction CO and Houston TX)

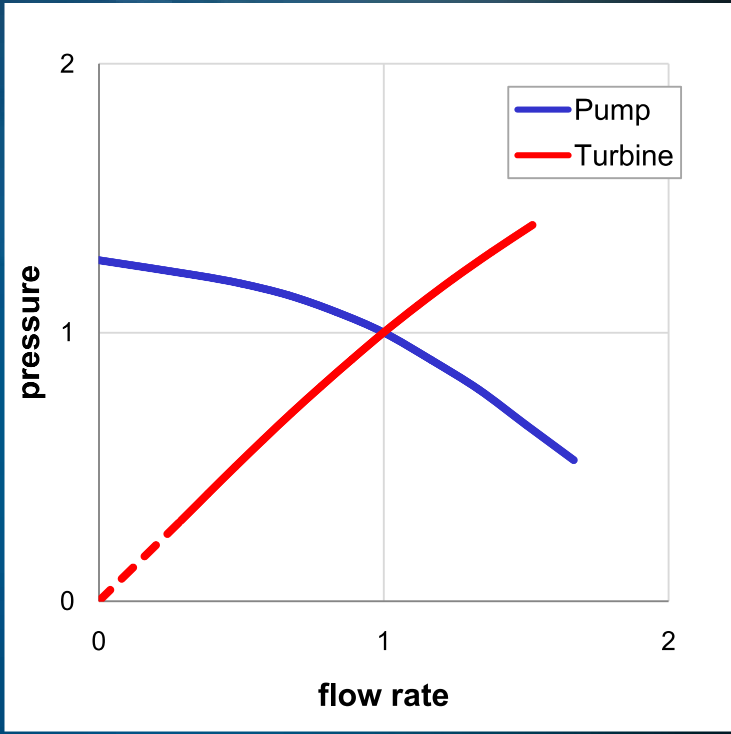
Design Conditions

- Design condition: maximum net power for each scenario – resource temperature, location and outlet temperature constraint
  - Fixed geothermal fluid flow rate
  - Working fluids: iC5, iC4, nC4, C3, R134a, R245fa
  - Incorporate realistic operating parameters (pinch points, efficiencies, ΔP's)
- Evaluate benefit of technologies not used in conventional hydrothermal plants
- Estimate capital cost based on predicted equipment sizes

Scientific/Technical Approach - continued

Off-Design:

- Fix equipment sizes for selected design condition
- Include effect of flow and temperature changes on heat transfer coefficients, efficiencies, ΔP's
- Account for effect of turbine on working fluid flow
- Identify conditions giving maximum power for different ambient and resource temperature conditions.
- Project power production over project life
- Evaluate the potential to decrease generation costs
  - Selection of design conditions for ambient and turbine
  - Other concepts (changing working fluids, allowing expansions inside two-phase region)



Relationship Between Turbine and Pump Flow

Scientific/Technical Approach - continued

Working Fluid Mixtures:

- Evaluate effect of composition and tube orientation on condensing film coefficient
  - Test data from Heat Cycle Research Facility
  - Tube orientations of 90° (vertical), 60°, and 15°
  - Isobutane and hexane mixtures (0 to 15% hexane)
  - Propane and isopentane mixtures (0 to 40% isopentane)
- Use data to refine predictive methods for condensing coefficients
- Integrate results into a condenser design model capable of evaluating the suitability of at least one commercially available design with these fluids
- Identify any potential issues with the design and provide recommendations

Scientific/Technical Approach - continued

Milestones:

Sep 10	Complete Task 1 – Analysis of impact resource decline and ambient temperatures on air-cooled binary plant output, and the potential to mitigate those impacts with existing technologies
Feb 11	Complete evaluation of effect of mixture composition and tube orientation on condensing film coefficients
Sep 11	Complete Task 2 – Assessment of the suitability of existing condenser designs for mixed working fluids

Decision Points:

- The methodology used to evaluate existing condenser designs – February 2011
- Selection of the commercial design to be evaluated (will be largely dictated by the data from the prior testing) – March 2011

Status:

- Designs have been established for both resource conditions at both locations, and the benefits from a design using recuperation identified
- Fixed plant design models will be completed in early May

Accomplishments, Expected Outcomes and Progress

- Design conditions determined for both resource temperatures at each location (design at mean annual air temperature)
- Benefit of recuperation evaluated for each scenario
  - Positive impact on power only if constraint on outlet temperature
  - No benefit at lower resource temperature
- Model is being modified to fix equipment and reflect impact of varying flow rates and temperature on heat transfer, efficiencies and Δpressure

Location	T,gf	Design with no outlet constraint	Design with outlet constraint	Design with Recuperation
Grand Junction	200°C	87.2 kW-s/kg	76.6 kW-s/kg	81.8 kW-s/kg
	150°C	41.5 kW-s/kg	41.5 kW-s/kg	40.5 kW-s/kg
Houston	200°C	76.0kW-s/kg	70.3 kW-s/kg	73.2 kW-s/kg
	150°C	32.8 kW-s/kg	32.8 kW-s/kg	32.4 kW-s/kg

Accomplishments, Expected Outcomes and Progress

Mixed Working Fluids

- Non-isothermal boiling and condensing allow heat transfer irreversibility to be reduced
- Prior work by Demuth and Whitbeck
  - +20% increase in plant performance
  - Cost benefit if well field development costs equivalent to or greater than plant cost
- Vaporization of mixtures
  - Replicate benefit with pure fluid in supercritical cycles
- Condensation of mixtures
  - Can not replicate with pure fluids
  - Prior work successful – in-tube condensation, non-horizontal tube orientation, water cooled condensers

Can benefits be achieved in air-cooled condensers?

Project Management/Coordination

- With determination that final year of funding would not be provided, project work scope and schedule were revised to focus on binary conversion systems
- Activity has been planned to maximize use of existing resources
  - Previously developed model of binary plants
  - Software platforms (Aspen) available at the INL
  - Prior work on the evaluation of binary turbine performance
  - Test data from the Heat Cycle Research Facility (mixed working fluids)
- Work has been planned to facilitate ‘learning curve’ of staff having no prior geothermal experience
- Cost and schedule are monitored and reported internally on a monthly basis

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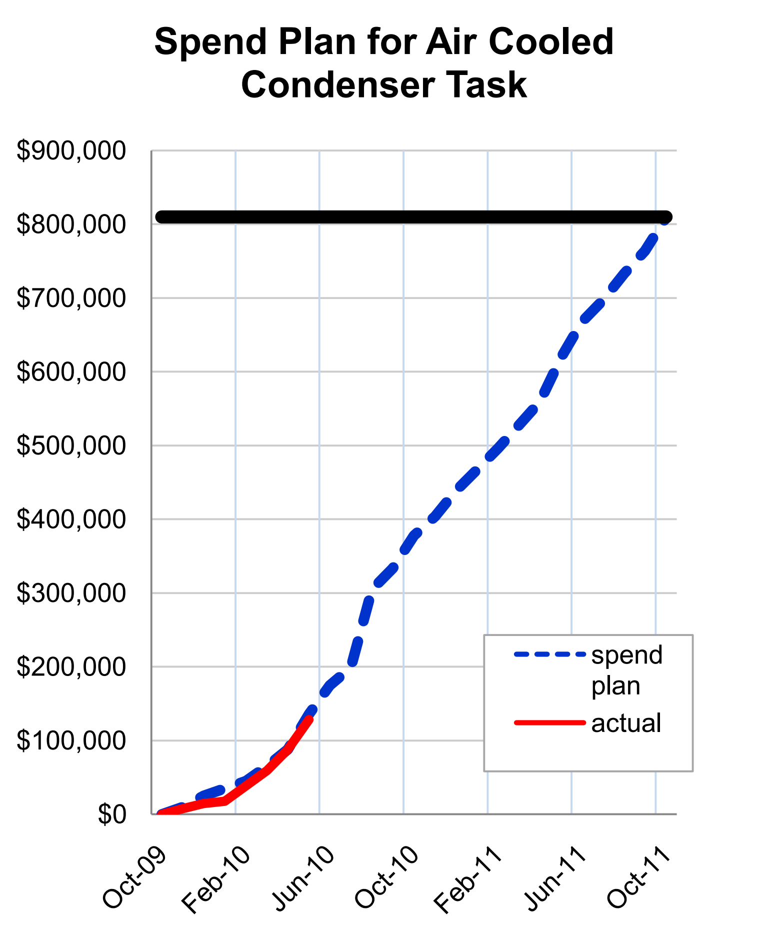
Project Management/Coordination

Air-Cooled Condensers in Next Generation Conversion Systems

ID	Task Name	Start	Finish
1	AIR-COOLED BINARY CYCLE	10/1/2009	8/31/2010
2	1. Identify concepts, scenarios, configure binary plant model	10/1/2009	3/1/2010
3	2. Determine performance benefits	1/15/2010	7/15/2010
4	3. Estimate Δcapital costs	5/3/2010	7/30/2010
5	4. Solicit industry comment	6/1/2010	7/30/2010
6	5. Document results/recommendations	7/1/2010	8/31/2010
7	AIR-COOLING WITH MIXED WF's	8/2/2010	9/30/2011
8	1. Use prior work to establish impact of mixtures on condensing coefficients	8/2/2010	2/1/2011
9	2. Evaluate suitability of selected Air-Cooled Condenser design for mixtures	2/2/2011	7/1/2011
10	3. Identify design deficiencies and changes needed	6/1/2011	8/15/2011
11	4. Solicit industry comment	7/1/2011	9/1/2011
12	5. Recommendations for further work	7/15/2011	9/15/2011
13	6. Final Report	7/1/2010	9/30/2011



Future Direction

Remainder of FY2010

- **Complete modeling of the effect of varying ambient temperatures and declining resource on binary plant output.**
- **Assess the selection of the design conditions for both the ambient temperature and turbine**
- **Identify concepts/technologies with the potential to lower generation costs**
- **Document findings**
- **Initiate work to examine condenser data from Heat Cycle Research Facility**

Future Direction

FY2011

- **Determine effect of mixture composition and tube orientation on condensing film coefficients during testing at the Heat Cycle Research Facility**
- **Use these results to evaluate predictive methods**
- **Incorporate best predictive method(s) into model to evaluate existing condenser designs**
- **Select most promising design and assess suitability for use with mixtures**
- **Document findings**

Summary

- The heat source and sink temperatures define the maximum power a cycle can produce
- This work seeks to minimize the impact of variations in the source and sink temperature on the performance of a plant once it has been constructed
- Benefits of technologies that are applied to mitigate effects of off-design operation will be dependent upon the scenario evaluated
- Working fluid mixtures
  - Increase performance and plant cost
  - Reduce contribution of well field and reservoir to generation cost – lower generation cost if non-plant costs are significant
  - Questions whether non-isothermal condensation can proceed in commercial condenser designs