"Design, Construction and Operation of CSP Solar Thermal Power Plants in Florida"

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Project Period: **Nov. 2008- May 2014**

Budget: **$882,000**

Project Description

Florida utilities are mandated to achieve 20% renewable energy contribution to their generation mix by 2020. While technologically feasible with solar energy, the capital costs are still high. This project targets the development of solar thermal power technology for bulk power and distributed generation, which will diversify energy resources in Florida and reduce greenhouse emissions by utilizing renewable sources. Also, there will be economic impacts with the establishment of new power industry in Florida, which will help the electrical utilities of the state to meet the renewable portfolio standards. The project has three main tasks; the first one is to develop design methodologies and standards for the proven solar thermal power technologies in combination with bio or fossil fuels based on Florida conditions and resources. Secondly, the project aims to set up demonstration and test facilities for these technologies for optimization for Florida conditions, and the final task is to develop and commercialize innovative technologies based on new thermodynamic cycles.

Universities: USF, UF, UCF

Research Objectives for Current Reporting Period: The main research objectives for the current reporting period include the development of a test facility and pilot demonstration systems based on parabolic trough technology.

Progress Made Toward Objectives During Reporting Period: This project consists of 4 tasks. The first 2 tasks were completed earlier and their reports were submitted. Task 3 is for design, installation and operation of a 50 kW CSP power plant. Task 4 is for the development of a thermal energy storage system for CSP power plants.

Design and installation of the solar field and the 50 kW power block have been completed. Fig. 1 shows the solar field and the power block of the 50 kW_e CSP solar power system. The Soponova 4.0 (Sopogy Inc.) parabolic trough collectors have been used in the solar field designed to provide 430 W/m^2 of thermal energy after losses. The power block that will convert the thermal energy to electricity is based on Organic Rankine Cycle. This power block has a nominal capacity of 50 kW_e. The power block uses a dry cooled condenser, which demonstrates the operation of a CSP power plant without using water. This is an important development as we try to reduce water consumption in solar thermal power. The power block will be commissioned in May 2014 which will complete the task 3 of this project.

A thermal energy storage system has been developed based on encapsulated phase change materials. This system can be used at this solar thermal power plant as well as any other solar thermal power plant. This development has reduced the cost of thermal energy storage from the present estimated $45/$kWh_{th}$ down to $15/$kWh_{th}$. This completes the task 4 of this project.

Fig. 1. Solar Field for 50 kW_e power generation

Task 1: Development of simulation and design methodology for parabolic trough and parabolic dish
The objective of the task one is to develop a simulation and design methodology for the parabolic trough and parabolic dish based technologies for Florida conditions. Solar radiation, solar collector and thermal storage topics are the subtasks, and following progresses have been made during the period.
This task was completed and its report was submitted earlier.

Task 2: Development of a test facility and pilot demonstration

The second task targets the development of a test facility and pilot demonstration systems based on parabolic trough and dish technologies. The experimental combined power and cooling setup will be used as a preliminary study of the demonstration system that will be developed.
This task was completed and its report was submitted earlier.

Task 3. Installation and Operation of 50kWe Solar Power Plant
Sopogy Inc. Honolulu, Hawai is the main contractor for installation and operation of 50kWe Solar Power Plant at USF. Parabolic collectors (Soponova 4.0) were received from Sopogy and were assembled. Power block for generating electricity from GulfCoast Green Energy was also received and installed. Power block is a Green Machine Elite 4000 manufactured by Electratherm. This machine will produce about 50kWh electricity from the thermal energy produces by solar field that will have 199 Soponova 4.0 parabolic concentrators from Sopogy Inc. Fig. 12 shows the photo of Electratherm power generator with air-cooled condenser. Installation and commissioning of the solar field is complete. Installation of Electratherm power generating unit is complete, commissioning of this system will take place in May 2014. Figures 2 to 5 shows various parts of the CSP solar power plant.

Fig. 2 Power block with air-cooled condenser

Fig. 3 Solar collectors showing the header connections

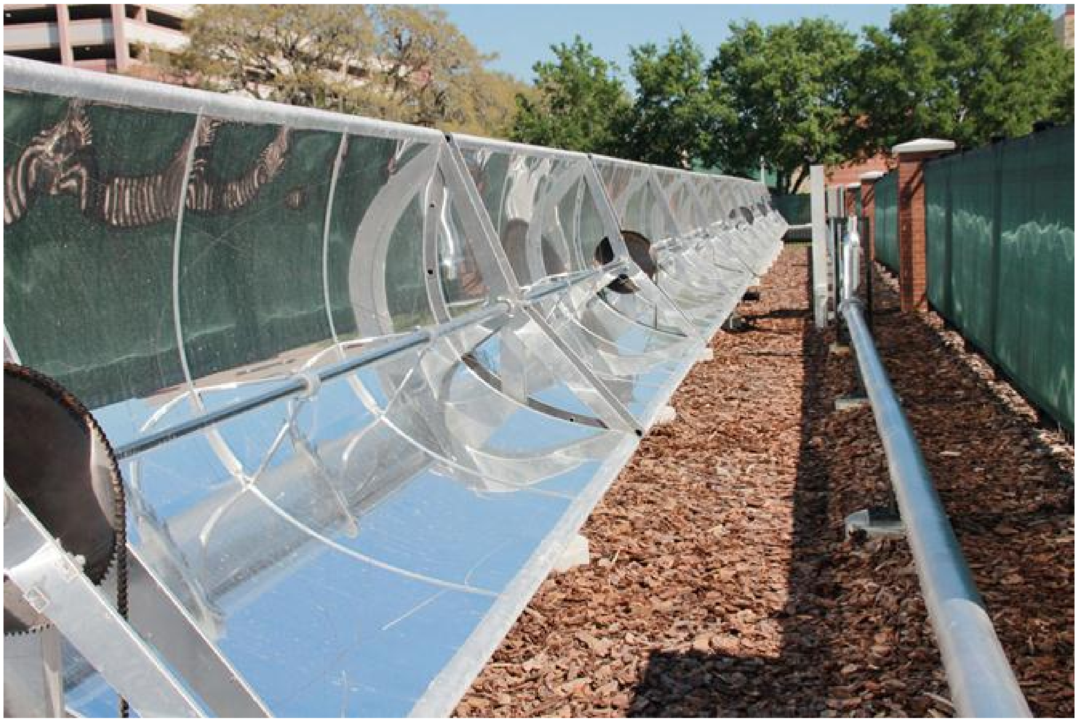

Fig. 4 A row of parabolic trough solar collectors

Fig. 5 Expansion tank and pump for the heat transfer fluid

Fig. 6 Pump, piping and expansion tank for heat transfer fluid flow to and from the collector field

Task 4: Thermal Energy Storage

We have developed a low cost thermal energy storage (TES) system for Concentrating Solar Power (CSP) based on encapsulated phase change materials (PCMs). The system will be able to meet the utility-scale base-load concentrated solar power plant requirements at much lower system costs compared to the existing TES concepts. This project is developing a TES system concept that will allow for an increase of the capacity factor of the present CSP technologies to as much as 75% and reduce the cost to less than $\$15/kWh_{th}$ as compared to the present cost of about $\$45/kWh_{th}$.

We have successfully prepared porous pellets of phase change materials that will allow for the volumetric expansion during PCM melting and hence impose less stress on the encapsulating material. We have developed the encapsulation techniques and selected the low cost encapsulating materials that will be used to encapsulate the PCM. The following pictures show some of the developed capsules.

Fig. 7 Ceramic encapsulated PCM for high temperature thermal energy storage

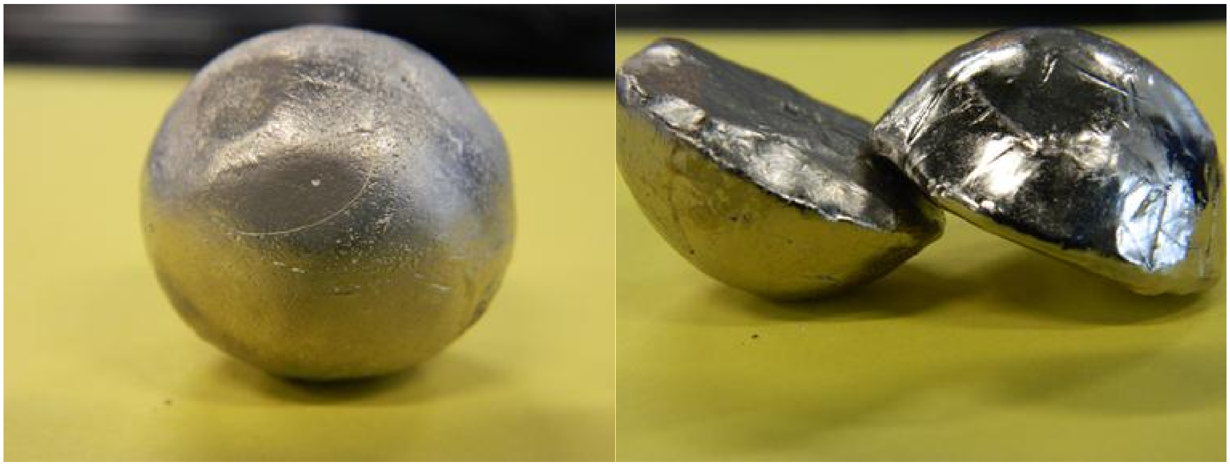

Fig. 8 Metal encapsulated PCM for medium temperature thermal energy storage

Publications

1. Besarati, S.M., Vasquez Padilla, R., Goswami, D.Y., and Stefanakos, E. (2013) "The potential of harnessing solar radiation in Iran: Generating solar maps and viability study of PV power plants," *Renewable Energy*, 53, pp. 193-199.
2. Chen, H. and Goswami D.Y. (2008) "The conversion of moderate temperature heat into power and refrigeration," in the Proceedings of the Annual Meeting of the American Institute of Chemical Engineers, Philadelphia, November.
3. Chen, H. and Goswami D.Y. (2009) "The conversion of moderate temperature heat into power and refrigeration with CO_2 and organic binary working fluid, in the Proceedings of biennial international student conference of Education without Borders", Dubai, UAE, March-April.
4. Chen, H. and Goswami D.Y. (2010) "Converting Low-Grade heat into Power using a Supercritical Rankine cycle with Zeotropic Mixture Working Fluid," in the Proceedings of ASME 2010 4th International Conference on Energy Sustainability, Phoenix, Arizona May.
5. Chen, H., and Goswami, Y. (2008) "Simulation of a Thermodynamic cycle with Organic Absorbents and Co_2 as Working fluids," in the Proceedings of the ASME 3rd International Conference on Energy Sustainability, Jacksonville, FL, August.
6. Chen, H., Goswami, D. Yogi, Rahman, M.M., and Stefanakos, E.K. (2011) "A supercritical Rankine cycle using zeotropic mixture working fluids for the conversion of low-grade heat into power," *Energy*, vol. 36 (1), pp. 549-555.
7. Chen, H., Goswami, D.Y., and Stefanakos, E.K. (2010) "A Review of Thermodynamic Cycles and Working Fluids for the Conversion of Low-Grade Heat," *Renewable and Sustainable Energy* Reviews, 14 (9), 3059-3067.
8. Chen, H., Goswami, D.Y., Rahman, M.M., and Stefanakos, E.K. (2011) "Energetic and Exergetic analysis of CO_2- and R32-based Transcritical Rankine Cycles for Low-Grade Heat Conversion," *Applied Energy*, 88, pp. 2802-2808.
9. Chen, H., M.M. Rahman, D.Y. Goswami, E.K. Stefanakos (2011) "Optimizing energy conversion using organic Rankine cycles and supercritical Rankine cycles," in the Proceedings of the Proceedings of the ASME ESFuelCell 2011 Conference, Washington, D.C., August.
10. Demikaya, G., Vasquez Padilla, R., and Goswami,D.Y. (2013) "A review of combined power and cooling cycles," *WIRES Energy Environ* 2013. Doi: 10.1002/wene.75
11. Demirkaya, G., Besarati, S., Vasquez Padilla, R., Ramos Archibold, A., Goswami, D.Y., Rahman, M.M., Stefanakos, E.K. (2012) "Multi-objective optimization of a combined power and cooling cycle for low-grade and mid-grade heat sources," *Journal of Energy Resources Technology (ASME),*134, 032002-1.
12. Demirkaya, G., Besarati, S.M., Vasquez Padilla, R., Ramos, A.A., Rahman, M.M., Goswami, D.Y., and Stefanaksos, E. (2011) "Multi-Objective Optimization of a Combined Power and Cooling Cycle for Low-Grade and Mid-Grade Heat Sources," in the Proceedings of the ASME ESFuelCell 2011 Conference, Washington, D.C., August.
13. Demirkaya, G., Padilla, R.V., Goswami, D.Y., Stefanakos, E., Rahman, M.M. (2011) "Analysis of a combined power and cooling cycle for low-grade heat sources," *International Journal of Energy Research*, 35 (13), pp. 1145-1157.
14. Goswami, D.Y. "Keynote address: Emerging CSP Market in India," SolarPACES conference, Berlin, Germany, September 2009.
15. Li, C., Besarati, S., Goswami, Y., Stefanakos E., and Chen, H. (2012) "Reverse osmosis desalination driven by low temperature supercritical organic rankine cycle," (pre press accepted and available online, October 2012) *Applied Energy*.
16. Li, C., Besarati, S., Goswami, Y., Stefanakos, E., and Chen, H. (2013). "Reverse osmosis desalination driven by low temperature supercritical organic rankine cycle," *Applied Energy*, 102, pp. 1071-1080.

17. Padilla, R. V., Ramos, A.A., Demirkaya, G., Besarati, S., Goswami, D.Y., Rahman, M.M., and Stefanakos, E.K. (2011) "Performance Analysis of a Rankine-Goswami Combined Cycle," Proceedings of the ASME 2011 "ESFuelCell 2011" (5th International Conference on Energy Sustainability and 9th Fuel Cell Science Engineering and Conference), Washington, DC, August.
18. Padilla, R.V., Demirkaya, G., Goswami, D.Y., Stefanakos, E., and Rahman, M.M. (2011) "Heat transfer analysis of parabolic trough solar receiver," *Applied Energy*, Vol. 88 (12), pp. 5097-5110.
19. Padilla, R.V., Demirkaya, G., Goswami, D.Y., Stefanakos, E., and Rahman, M.M. (2010) "Analysis of power and cooling cogeneration using ammonia-water mixture," *Energy*, Vol. 35 (12), pp. 4649-4657.
20. Padilla, R.V., Demirkaya, G., Goswami, Y., ad Stefanakos, E.K. (2010) "Parametric study of a combined power and cooling thermodynamic cycle for low temperature sources," in the Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition, 6, pp. 165-174.
21. Vasquez Padilla, R., Demirkaya, G., and Goswami, D.Y. (2009) "Parametric Study of a Combined Power and Cooling Thermodynamic Cycle for Low Temperature Heat Sources," in the Proceedings of the 2009 ASME Internaitonal Mechanical Engineering Congress and Exposition Conferenece (IMEC-E 2009), Lake Buena Vista, FL, November.
22. Vasquez Padilla, R., Ramos Archibold, A., Demirkaya, G., Besarati, S., Goswami D.Y., Rahman, M.M., ad Stefanakos, E.K. (2012) "Performance analysis of a rankine cycle integrated with the Goswami combined power and cooling cycle." *Journal of Energy Resources Technology, 134, 032001-1.*
23. Vidhi, R., Goswami, D.Y., Chen, H., Stefanakos, E., and Kuravi, S. (2011) "Study of supercritical carbon dioxide power cycle for low grade heat conversion," Proceedings of the Supercritical CO_2 Power Cycle Symposium, Denver, Colorado, May.