TITLE PAGE

1. PROJECT TITLE:

ENHANCED CONDENSATION TECHNOLOGY FOR ORGANIC RANKINE CYCLE

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3. Total project cost

Grant funds requested: $171,313
Match committed: $30,168

4. PREVIOUS PROJECT TITLE(S) AND/OR APPLICATION NUMBER(S) FOR GRANTS FROM THE RENEWABLE ENERGY FUND OR DENALI COMMISSION EMERGING ENERGY TECHNOLOGY GRANT PROGRAM:
NONE

5. PREVIOUS PROJECT TITLE(S) FOR ABSTRACTS SUBMITTED TO THE EMERGING ENERGY TECHNOLOGY FUND:

NONE

ENHANCED CONDENSATION TECHNOLOGY FOR ORGANIC RANKINE CYCLE

1. Project Summary

Project Description and Innovation

The proposed work is the investigation, optimization and testing of organic fluid condensation on a specially treated surface that enhances the vapor-to-liquid phase changing heat and mass transfer. A significant enhancement is expected to be attained, leading to cost saving in construction and maintenance of Organic Rankine Cycle (ORC) systems.

Generating electricity from low grade heat sources has attracted attention due to rising fuel price and increasing energy demand. The Organic Rankine Cycle (ORC) system is the most practical solution[1]. For this reason, a technical assessment of heat recovery with ORC for rural Alaska is being carried out by Alaska Center for Energy and Power (ACEP)[2]. However, the poor thermal properties of organic fluids hinder effective ORC implementation. The vaporization heat of a typical organic fluid is no greater than 500 kJ/kg while that of water is 2250 kJ/kg, which means a 4 to 5 times larger heat exchanger is needed compared to steam power plant to produce an equal power. According to a report by Department of Energy, almost half of total costs in construction and maintenance of an ORC system stem from its condenser[3].

The most significant source of irreversibility of the condenser in an ORC system is the thermal resistance due to the film of the condensate as described in Figure 1. When the organic fluid changes its phase from vapor to liquid on the condensing surface, the liquid condensate wets the surface and thus acts as a blanket that obstructs the heat transfer between the vapor and the coolant. We propose to enhance condensation of organic fluids by varying wettability of the condensing surface. In contrast to the film formed on a homogeneous surface (in Fig. 1), a heterogeneous surface alternating low and high surface free energy creates wavy profile on vapor-to-liquid interface. The heterogeneous surface promotes intense convection inside the condensate and as a result reduces the thermal resistance drastically. Figure 2 illustrates the convection induced by the heterogeneous surface. Typical condenser materials such as stainless steel, aluminum alloy, and brass possess relatively high surface energy; therefore liquid on it has low surface tension with

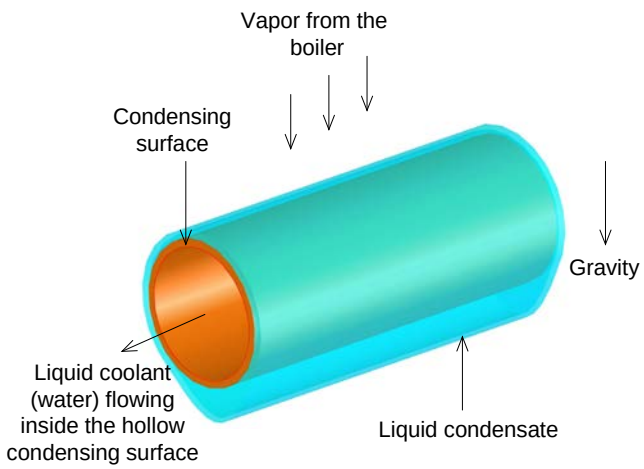

Figure 1: Traditional condensation. the condensate film obstructs condensation heat transfer

[1] S. Quoilin and V. Lemort, "Technological and Economical Survey of Organic Rankine Cycle Systems," 5th European Conference Economics and Management of Energy in Industry, Algarve, Portugal, 2009.

[2] http://energy-alaska.wikidot.com/organic-rankine-cycle-heat-recovery-system

[3] C. Kutscher and D. Costenaro, "Assessment of Evaporative Cooling Enhancement Methods for Air-Cooled Geothermal Power Plants," NREL Report CP-550-32394.

vapor. In contrast, liquid on the surface with low surface energy coating presents high surface tension. The fluctuating surface tension force of the liquid condensate acts like a stirrer in a hot pot and enhances the heat and mass transfer.

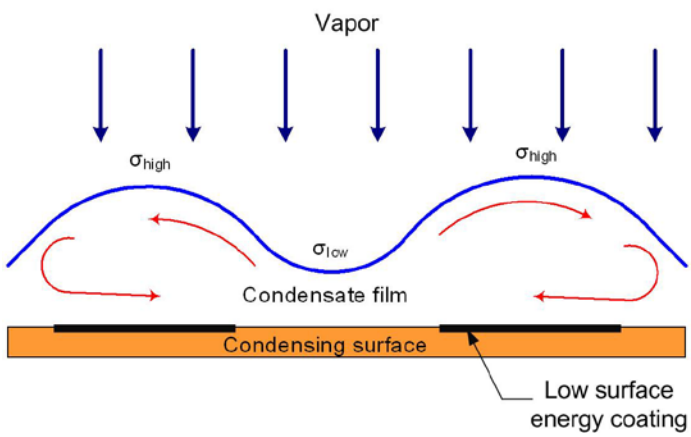

Figure 2: Convection induced by heterogeneous condensing surface

Research effort will be given to maximize the convection under a typical ORC condenser conditions. Firstly, a theoretical model that describes this convection effect will be developed. With the knowledge gained in theoretical analysis, we will identify design parameters such as wettability of the low surface energy coating layer, coating thickness, spacing between the low surface energy sections, and tilting angle with respect to gravity. During performance testing, design optimization will be carried out with a laboratory size condenser apparatus.

Project Eligibility

The proposed technology will improve the efficiency and effectiveness of existing Organic Rankine Cycle (ORC) systems. In addition, when it is applied to newly constructed ORC system, the size of condenser and pumping power for cooling water (or fan power for cooling air in case of air-cooled condensers) will be reduced. This is a considerable cost saving in that only operating cost for most ORC applications comes from pumping the coolant and the working fluid.

Project Priority

The proposed work will be carried on by a research group in the University of Alaska Fairbank and be supported by matching funds. The project is focused on reducing construction and maintenance costs in the waste heat recovery ORC systems for rural Alaska's diesel power plants.

2. Project Validation and Research Methodology

Objectives

The objective of this project is to enhance the condensation heat transfer in the ORC system by 100% through a heterogeneous condensing surface having high and low wettability. This enhancement will downsize the condensers in half and consequently reduce the required pumping work for coolant in half.

Methodology

The proposed project will be carried out within the Institute of Northern Engineering (INE) at the University of Alaska Fairbanks (UAF). INE was established for the purpose of multidisciplinary research in engineering, especially research under unique arctic environment. The Institute is housed in Duckering building and occupies over 10,000 square feet of laboratory and office space. The research program will be managed by UAF with respect to all administrative, financial and reporting requirements. The technical management of the project will be the

responsibility of the Principal Investigator (PI). This project will be housed in INE/UAF, and Dr. Sunwoo Kim will serve as the Principal Investigator for the project, assisted by a graduate student, Mr. Ramana Vanga.

3. Summary of Project Schedule and Budget

Intended project timeline is tabulated in Table 1. This is a two-year research project in which experimental investigations are conducted based upon a theoretical model development. Deliverables after completion of Tasks 1 and 2, Task 3, and Task 4 will be provided for the Alaska Energy Authority. The final report will include all research findings, results, conclusions, and discussion of commercialization.

Table 1: Project timeline

	Task description	Time (quarters)							
		1	2	3	4	5	6	7	8
1	Model development								
2	Design of condenser apparatus								
3	Construct of apparatus								
4	Initial performance testing								
5	Optimization of design parameters								
6	Reporting								

<u>Budget</u>

We are requesting funding for a total of 171,313. This includes funding for 1 month of salary and related benefits per year for SunWoo Kim, full support of one Masters-level graduate student for two years, and 80 hours and related benefits for two UAF staff. Total of $78,505.

A total of $26,500 is requested for supplies, primarily for the purchase of Condenser Building Supplies such as thermo-couples, pressure transducers, vacuum pump, heater and chiller parts, and for heterogeneous condensing surface, a data acquisition system, a laptop dedicated to this project, and miscellaneous laboratory supplies.

Funds of $5,829 are requested to support travel to one national-level conference (Washington, DC) per year to disseminate research results. Airfare costs are estimated at $1,350 per RT ticket. Per diem is estimated at $271 with an additional $165 requested per person per travel for ground transportation. Airfare and ground transportation increase by 10% annually to offset rising fuel costs. All pricing is based on current pricing, US Government figures, and UA Board of Regents policy.

A total of $1,000 is requested to fund publication costs, to defray the expenses of publishing our results in professional journals.

Funds of $1,600 are requested for conference registration costs.

UAF requires that any graduate student supported by a research project over the course of the academic year also receive tuition support for the life of the project. Costs in Year 1 are $14,760 (tuition) and costs increase by 10% annually, for a *total of $29520.*

Facilities and Administrative (F&A) Costs for research are calculated at 25% of the Modified Total Direct Costs (MTDC) for State Alaska Agencies. MTDC includes Total Direct Costs minus tuition and other student support, subaward amounts over $25,000, and equipment. A copy of the agreement is available at:

http://www.uaf.edu/files/osp/UA-FY-11-13-Pred-FA-Rate-Neg-Agrmt.pdf

Total indirect cost of project: $28,359.

To make this a more competitive proposal, UAF will supply 347 hours of salary and related benefits for the PI, for a total of $30,168.

4. Project Team Qualifications

The project team will consist of the Dr. Sunwoo Kim and his graduate research assistant. The PI, Sunwoo Kim is an Assistant Professor of Mechanical Engineering in the University of Alaska Fairbanks. He has contributed to the societies of renewable energy and phase-changing heat transfer by publishing numerous journal and conference papers. In his phase-change heat transfer research, he proposed an advanced dropwise condensation model for steam condensers, by which dropwise condensation phenomenon on super-hydrophobic surfaces can be predicted[4]. He also conducted dropwise condensation experiments where 200% and more enhancements were achieved[5].

5. Commercialization

The proposed technology can be adopted for both existing and newly constructed ORC condensers. For existing facilities, the heterogeneous condensing tubes can be replaced for old tubes at the end of their operation life. Scientific knowledge to optimize design parameters and coating technique are the key to a successful commercialization of the heterogeneous condensing surface. The former will be studied and obtained through the project period. Once the feasibility is proved, the proposed technology will be commercialized in a partnership with a capable coating company within five years. Possible partners include NEI Corporation, Lotus Leaf Coatings, and Optical Coatings.

By signature on this application, I certify that we are complying and will comply with the amount of matching funds being offered.

Andrew Gray, Director, UAF Office of Sponsored Programs

[4] S. Kim, K Kim, "Dropwise Condensation Model Suitable for Superhydrophobic Surfaces," Journal of Heat Transfer, DOI: 10.1115/1.4003742, Vol. 133, (8), 2011.

[5] K. Cheng, B Zhang, C Lee, M Kennedy, S. Kim, H Yoon, K Kim, J Liu, G Skandan, "Biomimetic Super-Hydrophobic Surfaces for Use in Enhanced Dropwise Condensation," SPIE Smart Structures/NDE, San Diego CA, 2011.