ELECTRO-OSMOSIS FOR DEHUMIDIFICATION

(Proof of Principle Study)

BACKGROUND

To achieve good comfort air conditioning systems must control both temperature and moisture levels. In a typical state-of-the-art system, air is cooled to a temperature lower than sensible load requirements to achieve the dehumidification needed. Therefore that process requires lower evaporating temperature than needed otherwise and results in increased operating pressure ratio for the compressor. In some applications, re-heating of the air is also necessary to achieve desired temperature and moisture condition. Independent dehumidification could provide a more energy efficient means of achieving the desired comfort level. Currently, moisture control methods using thermally activated desiccants are available but are not widely used because of cost and complexity.

The idea to use electro-osmosis for pumping water from one side of a barrier to the other or from space with lower partial pressure to one with higher partial pressure is not new. Several researchers have explored electro-osmosis in porous materials. Hock et al (1998) at U.S. Army CERL research lab presented results showing water transport through basement walls by using electro-osmotic "pulse" technology. They have been able to dry out the walls and even the air in the basement. Mina and Newell (2003) presented first results of their study. They have observed a pumping effect in the plaster wall covered with a layer of silica gel. . The wall had carbon electrodes on both sides. Applied potential was 5V and current was in the order of 10^{-4}A. Their derivation showed transport of approximately 2.3 g/m^2h of water. That indicates energy needed for transport to be 100 Wh/kg. The role of the silica gel layer was to absorb moisture from the air and prepare it for transport through the plaster layer. Data are provisional at this point but indicate potential.

Chen et al (2000) constructed an MEMS electro-osmosis pump using soda-lime glass. As opposed to the experiments by Mina and Newell the purpose was to pump water only. The piping and fluid reservoirs were etched in substrates thermally bonded together. The channel was 4.25 µm by 0.9 µm and 1 mm long. Their maximal increase in pressure was approximately 1 bar (14.7 psi) and the maximum flow rate was 2.5 µl/min. They used high voltage of 3 kV and current was around 7 µA. Based on that, energy for pumping only was 140 Wh/kg. They reported the efficiency of pumping to be only approximately 0.02% ($\eta = V\Delta p/P$).

The model used for explaining the basic principles is based on the fact that ions generated by an electric field "catch" molecules of water and "carry" them from one side of the membrane to the other. It appears that osmotic action is significantly stronger on liquid water than water vapor. That is the reason for use of the silica gel layer by Mina and Newell: to absorb moisture from the air and prepare it for transport through the plaster layer by electro-osmosis.

JUSTIFICATION OF NEED

There is constant demand for increasing the energy efficiency of air conditioning systems. The separation of dehumidification and cooling has a significant potential to increase the coefficient of performance of a refrigeration system by allowing a higher evaporation temperature. Certainly requirements for an efficient dehumidification process are essential because inefficient dehumidification could offset improvements in refrigeration efficiency.

For the assessment of the potential of electro-osmosis one should look into conventional vapor compression dehumidification units for the baseline value. Assuming average ratio of latent to sensible heat load at 50/50 and system COP of around 3, the value of energy needed for condensation is estimated to be around 200 Wh/kg. Assuming that data from above cited literature are correct, the potential for energy savings is obviously significant. Not only is there a potential for efficiency improvement due to increasing evaporation temperature because of separation of dehumidification, but the dehumidification itself may be more efficient. One should have in mind that the experiments cited reflect early concept development and need confirmation. Since these measurements were just the first steps in proving a concept one could expect additional potential improvement in pumping efficiency through optimization of design, parameters and materials.

OBJECTIVE

This research is proposed to be separated in two phases:

a) Preliminary Study – Design of an experiment based on a literature survey and formulation of a hypothesis.
b) Experimental evaluation – A follow-on phase contingent upon the result of the Preliminary Study

Phase I-Preliminary Study This phase of the project shall provide an assessment of the potential of the electro-osmosis process as follows:

- A critical analysis of the potential of the technology based on the published information.
- A formulation of hypothesis based on information in the literature and contractors own experience base.
- Design an experiment that can verify the hypothesis.
- Provide a report leading to a Go No-Go decision for Phase II.

Phase II -Experimental Evaluation The follow-on phase shall include:

- Laboratory experiments to provide data and refine the hypothesis.
- An assessment of the potential of the technology to compete with conventional vapor compression dehumidification capability.
- A final report summarizing the results from Phase I and II.

SCOPE OF WORK

Phase I

Task 1 - Literature Review

The contractor shall develop a critical analysis of the potential of the technology based on the published information. Part of the analysis shall be to identify practical means to realistically employ electro-osmosis for dehumidification.

Task 2 – Formulation of Hypothesis

The contractor should formulate the most plausible hypothesis of the physics of the phenomena based on information available in literature. The contractor should include even controversial observations like those of Mina and Newell who observed no effect of voltage polarity on the direction of water transport.

Task 3 – Design of Experiment

The contractor shall design an appropriate set of experiments to enable the PMS to make the Go No-Go decision to continue the possible Phase II effort. The experiment shall be designed to verify the hypotheses of fundamental phenomena from Task 2. The design should provide sufficient understanding of the main issues so that these experiment proposals should clearly lead to quantifiable data.

Task 4 – Phase I Milestone Report for Go No-Go Decision

The contactor should provide sufficient data and information for a clear Go No-Go decision.

Phase II

Task 5 – Conduct Verification Experiments and Refinement of Hypothesis

Assuming the decision is to go into the second phase this task will be the realization of the proposal developed in the Task 3.

Task 6 – Assessment of Potential of Technology

The contractor shall assess the potential for electro-osmosis for dehumidification to cost-effectively compete with the current means of achieving dehumidification. For assessment of the potential of electro-osmosis the contractor should use conventional vapor compression dehumidification units for the baseline value. The assessment shall include a payback analysis based on the energy to remove the same amount of moisture per hour as a function of relative humidity as a conventional residential vapor compression system removes under standard rating conditions.

Task 7 – Final Report

The final report shall summarize the results from Phases I and II.

REPORTING

The output from this project shall be a compilation of the information generated throughout the project. A detailed description of the testing conducted shall be included such that any laboratory skilled in the art could repeat the work.

The contractor shall provide the following:

1. Up to two, one-day progress reviews in the contractor's facilities, by not more than six ARTI representatives, to inspect the work-in-progress,
2. Monthly invoices,
3. Monthly letter update on progress and task results,
4. Draft technical report documenting the procedures, conditions, and findings, for review by and a presentation to an ARTI project monitoring subgroup,
5. Executive summary of the results,
6. Final technical report resolving review comments provided by ARTI,
7. Tabulated values for all measurements as an appendix to the final report (for measurements which are adjusted by correction factors, also tabulate the corrected results and clearly show the method used for corrections),
8. Technical presentation/paper of progress or final results to be presented at a conference in the continental United States of ARTI's selection,
9. Patent Certification, and
10. Property Certification.

The executive summary, final report, tabulated data, and technical presentation/paper shall be delivered in both printed and electronic forms.

DELIVERABLES SCHEDULE

The contractor shall deliver the following as scheduled:

Printed Reports:

Unless otherwise specified by ARTI, printed material will be delivered on standard 8-1/2 X 11-inch paper. All original reports to be provided single sided, non-bounded; suitable for subsequent photocopying.

1. Invoices..Monthly
2. Letter Reports on Progress.............................Monthly
3. Technical Papers/Presentations......................As needed by conference requirements
4. Draft Final Technical Report, Tabulated Data,
   Executive Summary,
   (1 original and 10 copies) ....60 days prior to contract completion date
5. Final Technical Report, Tabulated Data,
   & Executive Summary (3 originals) ....30 days after receipt of ARTI comments
6. Patent Certification ....With delivery of final technical report
7. Property Certification ....With delivery of final technical report

Electronic Reports:

Unless otherwise specified by ARTI, electronic documents shall be delivered on CD-ROM that integrates all text, figures, tables, photographs, etc. into a single-file Microsoft Word document and also into a single-file Adobe Acrobat PDF document. At least ten (10) copies of the CD-ROMS will be delivered unless a greater number is agreed upon between the successful contractor and the ARTI Project manager.

1. Technical Papers/Presentations......................30 days after submission or presentation
2. Final Technical Report...................................30 days after receipt of ARTI comments on the Draft Final Report

INSTRUCTIONS FOR PROSPECTIVE CONTRACTORS

Execution of Project

This project will be executed in two phases. Bidders must provide proposed budgets and schedules for each phase. Execution of the second phase will be an option at ARTI's discretion. The approval for the phase II to this project is contingent upon ARTI's acceptance of results from the first phase of the project, along with its acceptance of the methodology and the cost proposed. ARTI, at its own discretion, may sole-source the second phase of this project to the recipient of the initial phase of the project or open the second phase for competitive bids.

Level of Effort

Completion of both phases is expected within 18 months of elapsed time. The cost of the work for both phases is budgeted not to exceed $150,000. It is anticipated that the contract for this work will be awarded at a lower price based on selection from competitive proposals. However, price will not be the only factor weighed in the selection process. Prior experience and expertise in the field of study, access to laboratory and/or field sites required for completion of this project, and competitive prices will all be consider in selecting a contractor for this project.

Limitation

Solicitation of this project does not commit ARTI to award a contract, pay any cost incurred in preparing a proposal, or to procure or contract for services or supplies. ARTI reserves the right to accept any or all proposals received, or to cancel in part or its entirety a solicitation for this work prior to the signing of a contract agreement, when it is in ARTI's best interest. ARTI reserves the right to negotiate with all qualified sources.

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