“DESIGN OF EXPERIMENTS HEATS UP SOLAR ENERGY RESEARCH.”

by

Richard Burnham

With the aid of a powerful statistical tool called design of experiments, Dr. Keith Gawlik, a Senior Engineer at the National Renewable Energy Laboratory (NREL, Golden, Colorado), recently completed a successful three-year study to find the most cost-effective materials for solar air heaters. Building on earlier work performed by Dr. Charles Kutscher at the NREL, Dr. Gawlik examined unglazed, transpired solar air heaters. Interestingly, results of the study contradicted researchers’ expectations.

UNEXPECTED RESULTS

Transpired air collectors absorb solar energy on dark metal surfaces. A fan pulls ambient air through the holes in the heated metal, which is typically made of aluminum – an excellent heat conductor.

Dr. Gawlik’s study revealed that the effect of conductivity is minimal. Therefore, inexpensive, low-conductivity material, such as galvanized steel should be just as effective as costly, high-conductivity aluminum. Certain types of plastic may also perform effectively, although consideration must be given to the rigidity and strength of the material.

THE KEY BREAKTHROUGH

Dr. Gawlik used design of experiments (DOE) software (Design-Expert®, Stat-Ease, Inc., Minneapolis, MN) to study five factors each at two levels using a standard test plan. He began by ranking variables according to importance. The five factors selected were:

A. Pitch (center-to-center distance between holes in the perforated collector)
B. Diameter (diameter of each individual hole)
C. Thickness (thickness of the collector plate)
D. Mass flux (mass flow rate of the suction air per unit area of the collector surface)
E. Conductivity (material thermal conductivity).

He then entered high and low extremes for each of the five factors into the two-level factorial design builder in Design-Expert.

After performing the experiments, DOE analysis predicted that variation in conductivity (Factor E) created negligible differences in performance. As far as material and geometry go, the small influence was somewhat of a surprise. In fact, the design revealed that the greatest effect came from mass flux (Factor D).

CONFIRMED IN THE LAB

Dr. Gawlik validated the software's predicted results by performing confirmatory experiments. He created perforated flat plates of aluminum (with a conductivity of 216 watts per meter Kelvin) and styrene (with a conductivity of 0.16 watts per meter Kelvin). Each plate was about 1 foot by 1.5 feet by 0.063 inches thick, with hole diameter and pitch corresponding to the optimal values predicted by the DOE.

The plates were subjected to the same conditions used earlier in a computational fluid dynamics program simulation. They agreed with the predicted model. Thermal conductivity did not significantly affect solar air heater efficiency. Lab tests at NREL's Transpired Collector Test Facility confirmed both DOE analysis and computational fluid dynamics runs.

For example, at a typical mass flux of 0.02 kg/s-m2 and with one common geometry, the high conductivity plate had an efficiency of 72%. The low conductivity plate's efficiency was 70%. This difference of only 2% is remarkable considering the change in conductivity was over 1000 times.

ACCURACY AND TIME-SAVINGS

In explaining his findings, Dr. Gawlik states, "The use of the factorial analysis was very important because I was able to examine a number of different conductivities and configurations. The effect of going to a low-conductivity plate is very exciting."

Information gained in this study will enable manufacturers to produce more cost-effective systems, which should encourage greater use of solar air heaters.

States Dr. Gawlik, “I found that conductivity isn’t an issue until extremely low conductivity is approached, for example, the low conductivity values appropriate for materials that would be considered insulators, not heat conductors.”

Due in part to the success of this experiment, Dr. Gawlik is again using DOE in another study, this one related to heat transfer and fluid flow. He is examining the use of perforated material as a heat transfer enhancement surface. This material would be applied to tubes carrying a fluid or vapor that would be either rejecting or accepting heat from air. The fluid or vapor would then go through perforated fin-type structures attached to the tubes.

Not only has Dr. Gawlik and two collaborators earned patent number 5,692,491 for their low-conductivity collector work, NREL’s transpired collector technology for aluminum collectors also won a place in R&D Magazine’s 100 most important technology innovations of 1995. Currently, transpired air collectors are achieving efficiencies of more than 70% in some applications. Dr. Gawlik’s research may soon be adding even more fuel to residential owners – and saving them solar collector costs, too.

DESIGN OF EXPERIMENTS: A DEFINITION

DOE refers to any statistically optimized matrix of input factors. It falls into the category of planned experimentation, as opposed to just collecting chance data. Another form of planned experimentation is the traditional, less revealing one-factor-at-a-time (OFAT) approach. The OFAT approach cannot match the statistical power of DOE, which takes advantage of highly efficient parallel processing schemes embedded in the experimental matrix. Derived in the 1920s, DOE's complex hand calculations were too labor-intensive to be widely accepted -- until specialized software became available to automate the process.

Given the high cost of experimentation, the efficiency of DOE should be reason enough to abandon OFAT. But the most compelling argument against OFAT experimentation is that by its very nature it cannot reveal factor interactions. DOE does this extremely well, often proving to be the key to success.

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