10 - Thermoelectric 100 W warm water electricity generating unit. J. G. Stockholm, J. P. Buffet.in Proceedings 31st Power Sources Symposium, 11-14 June 1984. Electrochemical Society Inc.pages 19-22 organised by U. S. Army. Eradcom

THERMOELECTRIC 100 W WARM WATER ELECTRICITY GENERATING UNIT

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A thermoelectric unit that operates with two water circuits has been built, tested and has gone through extensive endurance tests (1). The application was to cool water but the system being reversible it has been operated in the electricity generating mode to validate a mathematical model that gives electrical performances. A 100 W unit, based on the proven technology, has been optimized for electricity generation.

DESCRIPTION OF UNIT

A photograph of the unit P 904- 336 without its casing is given in Fig. 1. The dimensions are 720x320x200 mm . It consists of two independent sets of straight metallic tubes that are linked in series by U bends, one set is for the warm water the other for the cool water. Each flow is by horizontal planes, alternately from the bottom up there are 3 warm and 2 cool planes of tubes. The general pattern is counter-flow.

Along each section of straight tube are placed 14 copper pieces that transfer the heat from the warm water through the thermoelectric material and to the cool water. The tubes are grounded and are electrically insulated from the copper pieces.

The thermoelectric material is commercially available grade from Melcor of Trenton N.J. The unit contains 168 couples, each piece has an area of 1.5 cm2 and thickness of 1.5 mm.

A unit of this design was vibration tested. The frequency was varied from 1 to 100 Hz a resonance was found around 90 Hz and the unit was vibrated at 10 g peak to peak for several hours. The unit's performances were the same before and after the testing.

Endurance tests consisting of thermal cycling every few minutes with temperature differences between 12 K and 18.7 K and have been done up to 20,000 cycles without any measurable variation in performances.

Tests have been done in the electricity generating mode with temperature differentials between the two liquids in excess of 50 °C, these conditions corresponded to temperature differentials across the thermoelectric material greater than 35 °C. No degradation was found after these tests.

MATHEMATICAL MODELLING

A model has been written using the classical equations of thermoelectricity (2). There are 10 simultaneous equations which are linear for 9 of the unknowns but the unknown : electrical intensity I is quadratic. A simple iterative procedure leads after 3 or 4 calculations to a convergence better than 1 %.

COMPARISON OF MODEL TO EXPERIMENTAL RESULTS

The unit described above was operated in the electricity generating mode. The fluid temperature measurements were put into the model with all the units' characteristics. The measured electrical output powers were between 0.1 and 1.9 % of the calculated values.

DIMENSIONING OF A 100 W UNIT

The unit P 904 - 336 can be scaled up to generate 100 W without changing any of the technology of the dimensions of heat transfer parts, the tubes were lengthed so that each tube has 24 copper pieces instead of 14. This unit is called P 904-576. The last 3 digits correspond to the number of thermoelectric pieces in the unit (corresponds to the number of couples x 2). The dimensions are 1088x300x225 mm.

The electrical power output is strongly dependent on the ratio r of the load resistance to the internal resistance of the unit (3). The electrical power output is plotted in Fig. 2 for the above unit as a function of r. The peak is for r = 1.27. It is generally accepted that the peak is at r = 1.

The influence of the thermoelectric material's dimensions and characteristics are examined.

- Thickness of thermoelectric pieces.
Using the model the thickness e of the thermoelectric pieces was varied between 0.5 and 1.5 mm, the maximum electrical output is for e = 0.65. This value has been retained as the optimum,sintered material can be sliced to this thickness but polycrystalline material is difficult to cut in thin slices, the minimum is between 0.8 and 1 mm with the latter thicknesses the output power is reduced by 2 to 4 %.

- Surface area of the thermoelectric material
The influence of the area of the thermoelectric piece associated with a given heat exchanger area is presented in Fig. 3. The curve indicates that the area of 1.5 cm2 per heat exchanger cold side area of 9.1 cm2 is the optimum, it corresponds to a ratio n of thermoelectric material to cold side heat exchanger area of 0.16. In this unit there are 3 layers of hot tubes and 2 layers of cold tubes.

ELECTRICAL POWER VERSUS FLUID TEMPERATURE DIFFERENCE

It has been shown how the electrical output varies with fluid temperature (4), to a first approximation it varies as the square of the temperature between the 2 fluids. Fig. 4 gives the calculated output,using our model ajusted on experimental measurements, versus temperature difference between fluids. The curve having the predicted shape of $y = ax^b$, where b = 2.00. The parameter a characterizes the efficency of a unit, but it is more meaningful to relate a to a characteristic dimension of the unit, several can be used : hot or cold side heat exchanger areas, area of thermoelectric material we have used the cold side heat exchanger area which is 0.524 m2 for the P 904-576 :

$$W(S) = 0.057 \Delta T^2$$

where W(S) is the electrical power in W per m2 of cold side heat exchanger.

The electrical power for the P 904-576 unit is

$W = 0.03 \Delta T^2$ where W is in watt

The output voltage at $\Delta T = 60$ k is 2.2 volts.

Another unit of the same technology with pieces of thermoelectric material with an area of 64 mm2 has a voltage which is doubled and the electrical output is reduced by less than 10 %.

CONCLUSIONS

A thermoelectric warm water electricity generating unit has been built, the performances have been measured and are unchanged after prolonged thermal cycling tests. Thermoelectric material dimensions are examined and for the technology used in the design the optimum thickness of thermoelectric material was found to be 0.65 mm. A mathematical model based on experimental measurements is used to predict performances of a unit with 576 pieces of thermoelectric material. To obtain greater electrical powers, several units can be put in parallel or in series electrically.

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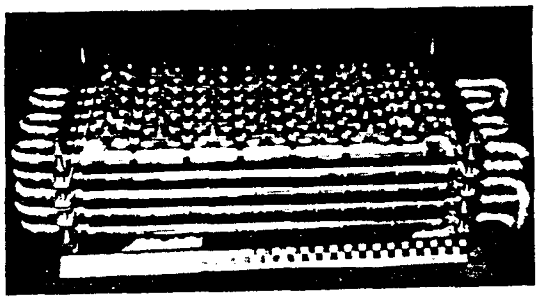

Fig. 1 - Photograph of unit
P 904-336

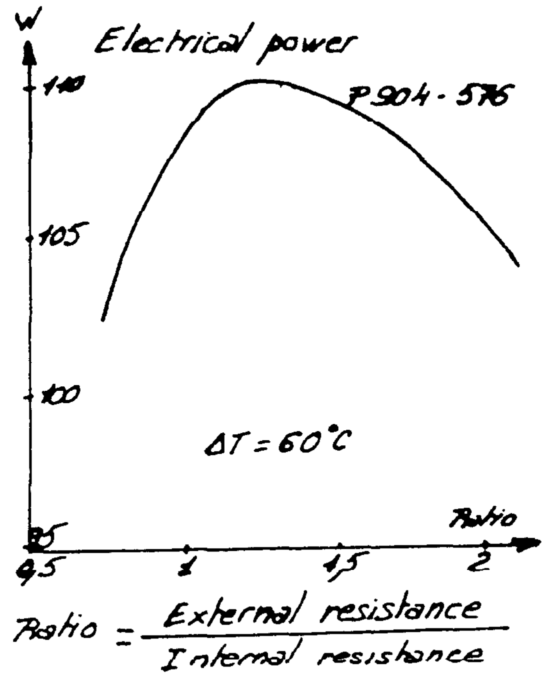

Fig. 2 - Electrical power versus the ratio of external resistance to internal electrical resistance

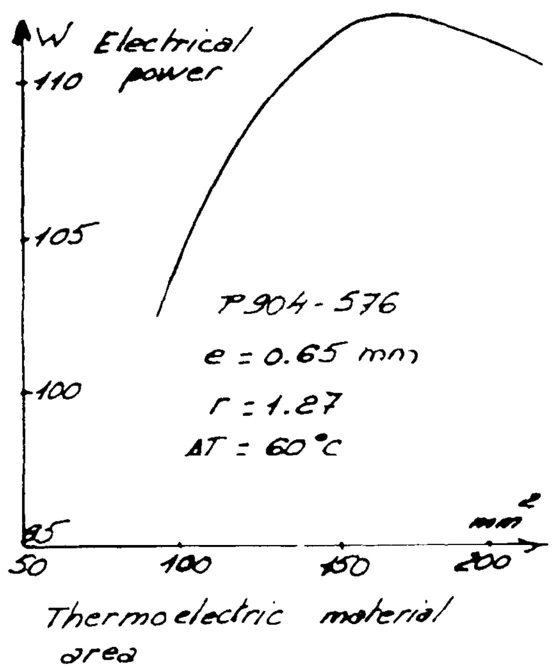

Fig. 3 - Electrical power versus Thermoelectric material area.

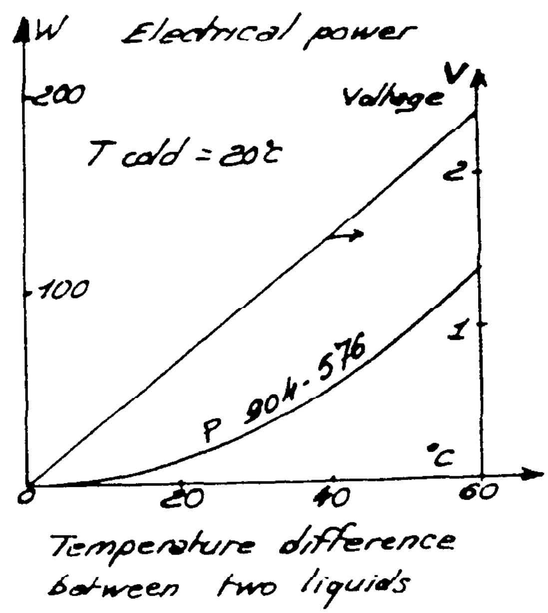

Fig. 4 - Electrical power versus temperature difference between liquids.