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WASTE HEAT THERMOELECTRIC GENERATORS

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An air to water thermoelectric unit has been built to study its operation as a heat pump and as an electricity generator The experimental results are used to validate a mathematical model. An original aspect of the technology is that it uses polarised modules. Operation with gas temperatures on the hot side up to 300°C, and on the cold side constituted by tubes with water at 35°C, gives powers up to 200 W. When waste heat is used, this electrical power can be very usefull.

1 DESCRIPTION OF UNIT EA 505

The overall dimensions of the unit are :
front : 405 x 540 mm
depth : 170 mm (along the air circuit)
mass : 34 kg
A front view photograph of the unit is given in Fig. 1.
The unit is composed of 10 tubes of 400 mm that are in series along the water circuit. The air heat exchangers have aluminium pins.
The unit contains 240 polarised modules (1) which have each an odd number of thermoelements, they are alternately of N type and of P type along the electrical circuit constituted by the heat exchangers.
The water tubes are grounded.
A schematic of the assembly is given Fig. 2.
The characteristics of the thermoelectric modules (19 * 19 mm) are : 25 thermoelements of bismuth telluride
Cross section : 4.58 mm² ; height : 1.65 mm
The air heat exchanger per module :
. Base plate:52*26 mm;pins diameter 2.8 mm;height 24 mm.
Number of pins : 34
The water heat exchanger per module :
. Lenght of tubing : 24 mm ; diameter : 17 mm
The electrical resistance of the thermoelectric generator is 22.9 Ω at 27° C (300 K).

2 MATHEMATICAL MODELLING

A model has been developped by J.P. BUFFET (2), (3).
The flow rates, inlet and outlet temperatures of fluids are entered into the model.
It calculates ; thermal powers, electrical current and voltage, and interface temperatures of the thermoelectric module.

3 COMPARISON OF MODEL TO EXPERIMENTAL RESULTS.

The object of these electricity generating measurements is to validate and adjust the mathematical model.

3.1. Experimental parameters

The following parameters were measured :
- electrical parameters V and I
- internal (R) and external (R_L) electrical resistances
- fluid flow rates, inlet and outlet temperatures
- interface temperatures of two of the thermoelectric modules.

3.2. Experimental results

Tests were done for two values of temperature difference ΔT_f between the fluids, of 50 K and of 70 K
The external electrical resistance R_L is varied between 0 and 1.5 times the internal resistance of the generator.
The electrical power versus fluid temperature difference ΔT_f is plotted in Fig. 3., the X-axis scale is chosen as ΔT_f^2 so that the power curve becomes linear.
The unit gives 32 W of power at 28 Volts with ΔT_f = 70 K.
The air heat transfer coefficient h is considered to be the least well known parameter of the thermoelectric generator.
Previous experimental measurements have shown that it is of the form :

$h = A * V^B$ h in W / (m^2.K), V in m/s

The experimental results with air temperatures up to 90°C confirmed that this function is still valid, the values found for A and B are : A = 21.9 ; B = 0.825.

4. LIMITS OF OPERATING RANGE

There are 3 limiting aspects :
- thermoelectric module

  Bismuth telluride can be used over a wide range of temperatures from well below 0° C to over 200° C.
  Interface solders that melt below 200°C are often used so they constitute the limiting interface temperature.
  We have considerable experience up to a maximum hot face temperature of TE material of 100° C.
  Thermoelectric modules are available on the commercial market designed to withstand temperatures in the 200° C range.

- <u>liquid circuit technology</u>
  The liquid circuit consists of metallic tubes (copper alloys, stainless steel, titanium ...). Practical limitations of such circuits depend on the material that constitutes the seal, more than on the material of the tubes
- <u>gas circuit technology</u>
  The range depends considerably on the material used for the heat exchangers and the corrosive effects of the gas. Aluminium and copper can be used up to 200° C in clean, non condensing air.
  Stainless steels are interesting for corrosive gases and where one can afford a higher thermal drop across the air heat exchangers than for aluminium or copper exchangers. Gases up to 250-300° C can be used, remembering that the hot face temperature of the TE module must not exceed 200° C.

5 DIMENSIONING OF A 100 W UNIT

From the limitations indicated, we shall examine two examples : one with aluminium air heat exchangers, one with stainless steel air heat exchangers.
The calculations are done for a unit similar to the one tested (EA 505, with the same heat exchangers dimensions and the same number of polarised modules i.e. 240)
Each module contains 35 thermoelements of cross section 2.56 mm² and height 1.5 mm.
The thermoelectric material is a sintered bismuth telluride optimised for temperatures between ambiant and 200°C. The internal and load resistances are both of 90Ω.
The pressure drop on the air circuit for a flow rate of 0.14 kg/s is of 8 Pa.

5.1. <u>Aluminium air heat exchangers</u> EA 505 A

A unit is calculated for operation between 150 and 200°C inlet air temperature. The cold source is water at 35°C.
The electrical power and the voltage are given in Fig.4 as a function of air inlet temperature.
This unit produces between 50 and 100 W, the voltage is between 50 and 100 V.

5.2. <u>Stainless steel flue gas heat exchangers</u> EA 505 S

The dimensions of the heat exchangers are the same as the one above, except that the material is stainless steel with a thermal conductivity of 15 W/(m.K). The electrical power and voltage are also given in Fig.4.
The flue gas temperature range is between 200 and 320°C.
This unit produces between 70 and 200 W with a voltage between 80 and 130 volts.

6 CONCLUSIONS

A prototype unit has been tested in the laboratory with an air temperature up to 90°C. The unit contains bismuth telluride material normally used for heat pumps and for thermoelectric material temperatures below 80°C. The experimental data validated the mathematical model. This model is used to calculate two units using bismuth telluride optimised for electicity generation. A 75 W unit with aluminium air heat exchangers is calculated, the same design with stainless steel heat exchangers gives around 150 W. A new type of thermoelectric generator is derived from a heat-pump technology developed by the authors. It constitutes a considerable improvement over the classical technology of sandwiching medium size thermoelectric modules between large flat plates. The advantages of the new technology are : simplicity, robustness, modularity and low cost. Tests so far have been limited to a unit using heat-pump bismuth telluride with aluminium heat exchanger. The next step is to built a prototype based on our calculations which uses electricity generation type bismuth telluride. When stainless steel heat exchangers are used, some effort must be put into determining the best material for the seals.

The domain of application is essentially where waste heat : flue gas or hot air, is available. For example, a small electricity generating unit to power pumps and fans of cooling systems operating directly on waste heat. This would enable the system to be independant of an outside electrical power source. Another example could be a cheap back-up electrical power supply operating with a small burner to power a battery for an electrical starting system of some large equipment.

REFERENCES

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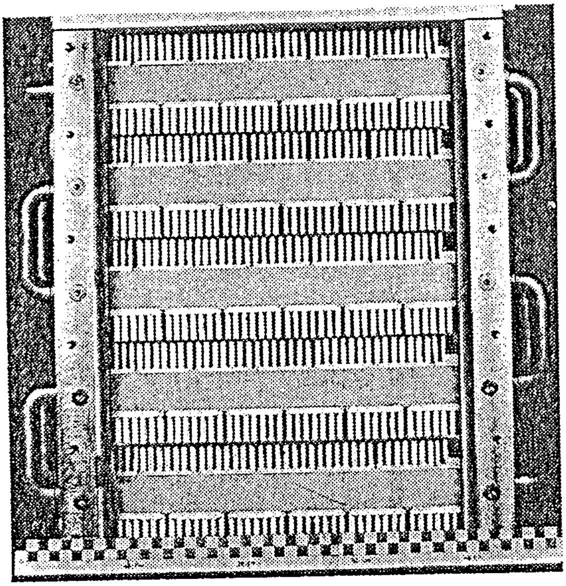

Fig. 1 - Prototype EA 505 - Front view

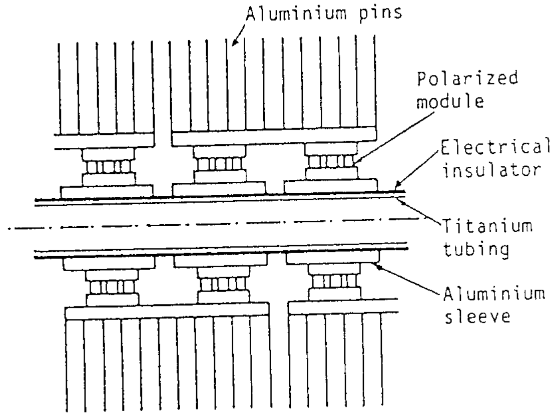

Fig. 2 - Schematic of assembly

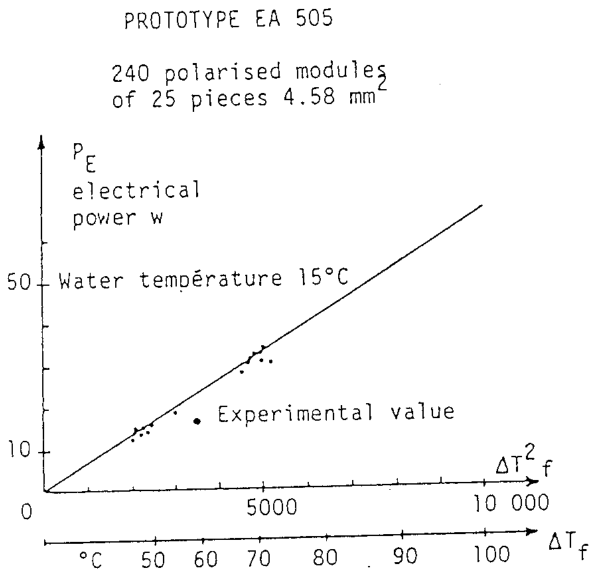

Fig. 3 - Experimental electrical power vs fluid ΔT_f

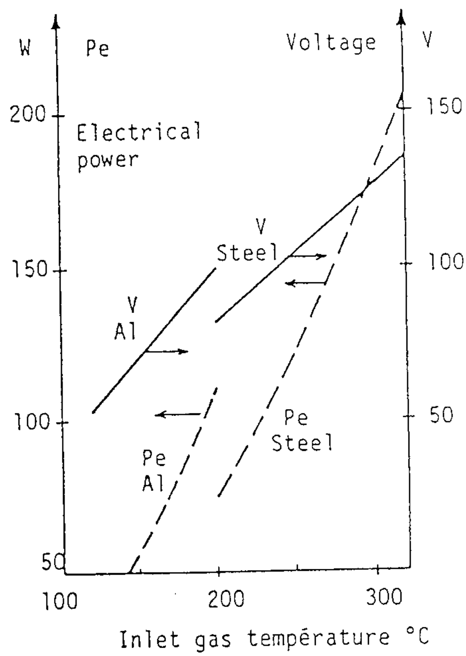

Fig. 4 - Calculated electrical power and voltage for two units :

EA 505 A :
Aluminium air heat exchangers
EA 505 S :
Stainless steel flue gas heat exchangers