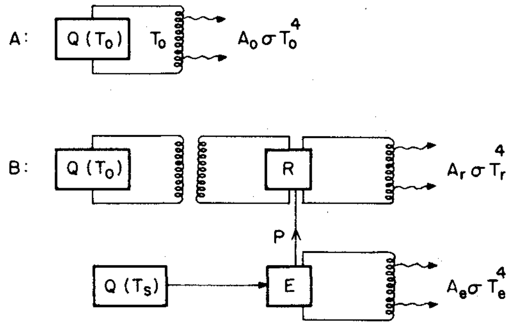

Fig. 1 Schematic diagrams of heat rejection systems: A) direct heat rejection and B) heat rejection via heat engine operating from source at T_s/T_0.

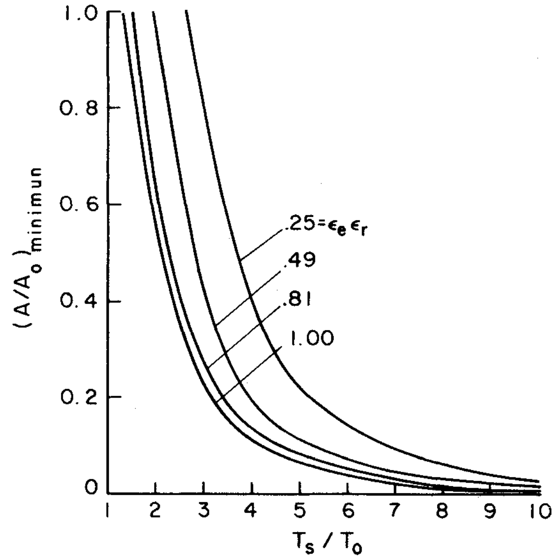

Fig. 2 Ratio of minimum radiator area to that for direct heat rejection, as a function of the ratio of the heat engine source temperature to the waste heat source temperature.

reduction in radiator area is about a factor of 16 for $T_s/T_0 = 5$ and a factor of 100 at $T_s/T_0 = 9$, which admittedly implies a high T_s.

The advantage is, of course, less for real engines than for Carnot engines. Assuming the same temperature ratios as for the idea case, we find for the (approximate) minimum radiator area,

$$\left(\frac{A}{A_0}\right)_{\min} \approx \left(\frac{4}{3}\ \frac{T_0}{T_s}\right)^4 \left[1 + \frac{3(T_s/T_0) - 4}{\epsilon_r \epsilon_e}\right]$$

from which it is clear that $(A/A_0)_{\min}$ retains its approximate inverse cubic dependence on T_s/T_0. This result is also plotted on Fig. 2 for a range of values of the product $\epsilon_r \epsilon_e$. Current highly refined heat engines can achieve values of ϵ in the order of 0.6-0.7, so $\epsilon_r \epsilon_e = 0.49$ is not unreasonable. For this case, we see a reduction in radiator area of about a factor of 10 for $T_s/T_0 = 5$. Reoptimizing the temperature ratios for the nonideal situation would decrease $(A/A_0)_{\min}$ somewhat.

Conclusion

While the magnitude of the gain that can be realized must be determined by quantitative design studies and, in any case, will depend on the temperature level of the heat source and on the degree of perfection of the refrigerator and engine, it does appear that substantial reductions in system mass can be realized by the heat rejection concept proposed here. In view of the high cost of transportation to orbit, the concept seems worthy of quantitative evaluation.

Recent Experiments with the Eindhoven MHD Blowdown Facility

W.J.M. Balemans,* A.J.D. Lambert,*
H.R.M. van Lierop,* P. Massee,*
W.F.H. Merck,* E.M. van Veldhuizen,*
and L.H.T. Rietjens†
Eindhoven University of Technology
Eindhoven, the Netherlands

SIGNIFICANT enthalpy extractions were obtained in early power runs of the closed-cycle MHD blowdown facility at the Eindhoven University of Technology (EUT). During run 303 in the fall of 1981, a maximum electrical power output of 362 kW (enthalpy extraction of 7.2%) was attained.[1] However, during power runs in 1982-1984, the power output varied substantially from run to run and the power level of run 303 could not be reproduced. In 1984, the available data were analyzed and the conclusion was reached that the large spread in power output was caused by 1) imperfect mixing of the cesium seeding; 2) load resistors having significant self-inductance, thus hampering the creation of streamers; 3) metal inlet and outlet parts inside the magnetic field (for reasons of structural strength) leading to short circuiting in the outlet region; and 4) different levels of molecular impurities during the various runs.

Recent experiments with the MHD blowdown facility performed in October 1985 were very successful. In connection with the mentioned analysis, the following modifications were introduced: 1) the single atomizer (Hartman whistle principle) was replaced by a system with two atomizers; 2) load resistors with negligible self-inductance were installed; and 3) the first part of the supersonic diffuser was redesigned and built up from small boron nitride tiles bolted to the cooling plates (see Fig. 1). In addition to these modifications, it was planned not to use the first run of a measurement series for power generation, since the analysis had also shown that the first run always produces a large amount of molecular contaminants caused by the degassing of the walls of the MHD generator. Table 1 shows the parameters of the various runs of the recent measurement series. Particularly, it is clear that the amount of water contamination decreased significantly after run 701, although the numbers given for H_2O and N_2 during run 703 are still about a factor two higher than those measured during the test series in 1981.

It is clear from Table 1 that the resulting power outputs of measurement series 7 are, to a large extent, reproducible. Run 703 produced an electrical power output of 423 kW (see Fig. 2), to date the maximum in this facility. The electrical power generated in these experiments is also an order of magnitude larger than the power produced in any other similar closed-cycle (noble-gas) MHD experiment in the world. Further, it is very promising that the construction of the MHD generator and the first part of the supersonic diffuser did not create problems during this measurement series. The supersonic diffuser shown in Fig. 1 can be used for the next measurement series without repair or modification. The electrically isolating construction of the supersonic diffuser has apparently also led to a decreasing static pressure in the second half of the MHD generator, with the axial distance even at a power output of

Received Jan. 9, 1986; revision received May 23, 1986.

*Research Associate, Department of Electrical Engineering.
†Professor, Department of Electrical Engineering.

Table 1 Parameters of various runs of measurement series 7[a]

Run	T_s	P_s, bar	Massa flow, kg/s,	B, max, T	R_L, Ω	C_s %	P_{th}, kW	P_e, max, kW	η_{ent}, %	H_2O, ppm	N_2, ppm
701	1820	7.0	4.9	4.8	5.6	—	4660	—	—	800	200
702	1920	7.2	5.0	5.2	5.6	0.11	4970	393	7.9	150	100
703	1910	7.2	5.0	5.1	5.6	0.11–0.20	4950	423	8.5	125	100
704	1890	7.2	5.0	5.3	7.3	0.14	4900	300[b]	6[b]	500	
705	1860	7.2	5.1	5.2	7.3	0.13	4900	273	5.6	500[b]	
303	1900	7.4	5.1	5.1	6.0	0.14	5030	362	7.2	50	200

[a] T_s = stagnation temperature, p_s = stagnation pressure, B = magnetic induction, R_L = load resistances, C_s = molecular fraction of cesium, P_{th} = thermal power input, P_e = electrical power output, η_{ent} = enthalpic efficiency, H_2O = water contamination level, and N_2 = nitrogen contamination level. [b] Estimated value.

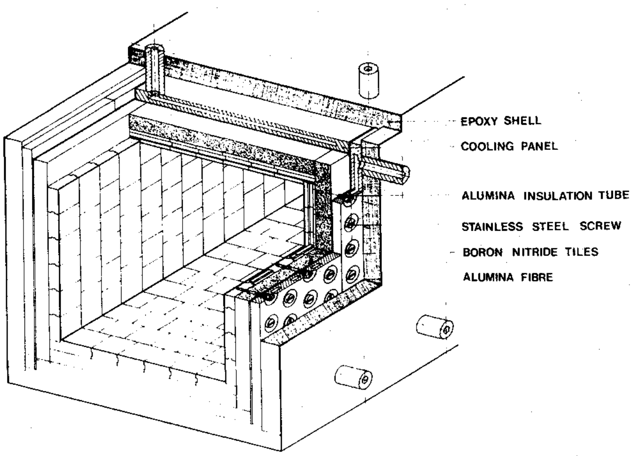

Fig. 1 Supersonic diffuser.

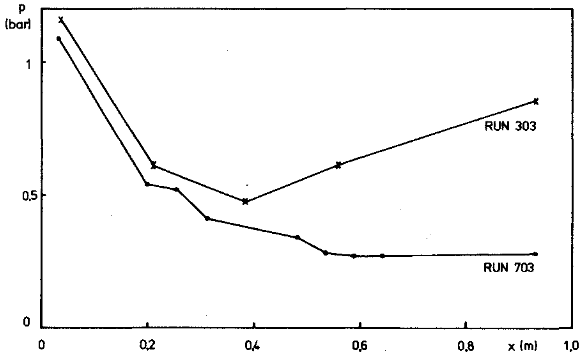

Fig. 3 Static pressure comparison, runs 303 and 703.

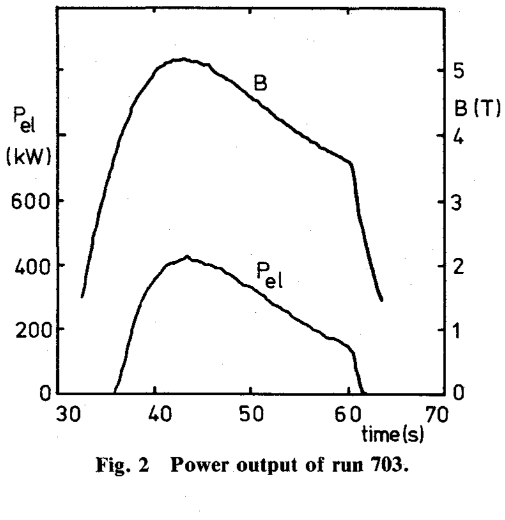

Fig. 2 Power output of run 703.

423 kW (see Fig. 3).[1] This is the first time that such a variation of static pressure, which corresponds with theoretical predictions of the available models, has been observed in a blowdown facility.

In the past, the pressure increase at the end of the generator was considered a major cause for limiting the power extraction. Now, it is concluded that this pressure increase is not due to power extraction, but to the electrical short circuiting in the supersonic diffusor. Since the pressure remained low during run 703, it can also be concluded that the electrical power output can be further increased by decreasing the values of the load resistors. Another improvement of measurement series 7 is that the fluctuation level of the diagnostical signals is much lower. This is attributed to the double atomizers and the low inductance of the load resistors.

The reasons for the high power output of run 303 were the low amounts of contamination and the fact that only during series 3 did the load resistors at the first seven electrode pairs have a very low self-inductance. Later, this led to the conclusion that low self-inductance is important.

During the runs, several static pressures have been measured with frequencies of 1 and 10 kHz, which opens up the possibility of determining velocities by means of correlation techniques. The same possibility is present with optical signals that have been measured simultaneously through three pairs of windows. Further, local velocity measurements have been performed by means of the dual-beam Laser Doppler technique. Results of the velocity measurements have to be interpreted and, together with other details of the measurement series, will be reported more extensively in the near future.

Acknowledgments

The authors recognize the superb technical support from A.P.C. Holten, H.J. Mennen, J.Th.W.J. Nouwen, A.E. Pfeiffer, A.G.C. van Stratum, and C.H.F.M. van de Weem.

This work has been carried out with support of the Netherlands Technology Foundations (STW).

References

[1]Massee, P. et al., "Gasdynamic Performance in Relation to the Power Extraction of the Eindhoven MHD Blow-Down Facility," *20th Symposium on Engineering Aspects of MHD*, University of California, Irvine, CA, 1982, p.7.4.1.