TID/SNA--313

m001-TRU04-W236a2

DESCRIPTION OF THE HYPERTHERMAL
ENVIRONMENT SIMULATOR (HES), A ONE-MEGAWATT
PLASMA GENERATOR FACILITY

September 1970

MASTER

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET-GENERAL

MICROFILMED

TECHNICAL DOCUMENT CENTER
Nuclear Rocket Operations

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DOC. NO. N-2300

AGCS 0120-48

X

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

M001-TRU04-W236a2

DESCRIPTION OF THE HYPERTHERMAL
ENVIRONMENT SIMULATOR (HES), A ONE-MEGAWATT
PLASMA GENERATOR FACILITY

C. M. GRACEY
D. M. JASSOWSKI
RESEARCH LABORATORIES
AEROJET LIQUID ROCKET COMPANY

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

CLASSIFICATION CATEGORY

UNCLASSIFIED

CLASSIFYING OFFICER

9-24-70
DATE

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET-GENERAL CORPORATION

ABSTRACT

The Hyperthermal Environment Simulator (HES) is a high-pressure one-megawatt plasma gas generator capable of providing rocket-engine gaseous combustion products at heat-transfer conditions similar to full-scale rocket conditions. In recent years its use as a rocket-engine simulator has extended material technology and system designs considerably. Also, along with the many test programs conducted have come new innovations to the HES system which have extended the operational capability of the unit as well as lowered test costs. To acquaint others with these advances and to assist them in their future test programs, the enclosed report provides a brief synopsis of the operational and performance aspects of the HES.

CONTENTS

	<u>Page</u>
I. Introduction	1
II. Discussion	1
III. Conclusion	11
Reference	23

FIGURES

<u>No.</u>		<u>Page</u>
1	Schematic of HES Plasma Head and High Pressure Chamber	3
2	HES Plasma Head and Test 5 Chamber	5
3	Schematic of Nozzle Fixture Housing to HES Plasma Gas Generator	6
4	HES Plasma Head and Nozzle Fixture	7
5	Schematic of HES System	8
6	Schematic of HES Power Supply	9
7	HES Control Console	10
8	HES Instrumentation Console	12
9	Tungsten Specimen Test Assembly	13
10	Silver Infiltrated, Tungsten Specimen Exposed in HES Plasma Gas Flame	14
11	Tungsten-Rhenium Thermocouple Installed in HES Pressure Chamber	15
12	HES Chamber Set-up for Testing Ceramic	16
13	Ceramic-Coated Tube-Specimen	17
14	HES Plasma Head and Uncooled Nozzle	18
15	Fibrous Graphite Nozzle Specimen and Housing Assembly	19

TABLES

<u>No.</u>		<u>Page</u>
1	Hyperthermal Environment Simulator (HES); Performance and Application	2
2	Typical HES Programs and Performance Achieved	20
3	Assembly Drawing Applicable to the HES System	22

I. INTRODUCTION

The Hyperthermal Environment Simulator (HES) is a high-pressure, 1 Mw, plasma-generator facility located in the Aerophysics Laboratories of the Aerojet Liquid Rocket Company. Developed to produce a controlled rocket-motor combustion environment for heat-transfer and materials studies, it has a wide range of capabilities. Nominal performance is listed in Table I.

The HES system can operate at pressures up to 550 psig, at gas temperatures to 8,000°F, and at flow rates between 1 and 20 lb/min, depending on gas composition and enthalpy required. At maximum power, in excess of 1.2 Mw, the system has a duration of 5 min. Durations of 1 hr are possible below power levels of 0.5 Mw. The unit has been run with nitrogen, hydrogen, helium, argon, nitrogen-hydrogen mixtures, and simulated propellant combustion mixtures including carbon dioxide, carbon monoxide, hydrogen, hydrogen chloride, nitrogen, oxygen, and water.

II. DISCUSSION

The HES plasma generator and test chamber are shown schematically in Figure 1. The unit has a tungsten-copper cathode and anode with an arc that has combined gas, magnetic-field, and wall stabilization. Depending on required composition and enthalpy, gases are introduced at the cathode, anode, or mix chamber. Here they are heated, mixed, and then passed through an interchangeable nozzle into the test chamber. During startup nitrogen, or some similar easily ionized gas, is delivered to the arc; and switch-over to other gases is performed generally within 5 to 10 sec after ignition.

The chamber is maintained at the required pressure by a separate gas flow. This allows chamber pressure to be set at any required value, independently of test-gas flow and enthalpy. Pressure can be changed during operation, as can power input and gas composition.

TABLE I

HYPERTHERMAL ENVIRONMENT SIMULATOR
(HES); PERFORMANCE AND APPLICATIONS

1. Performance

Chamber Pressure	Up to 550 psig
Temperature	3000 to 10,000°F
Gas Composition	N ₂ , H ₂ , O ₂ , H ₂ O, CO, CO ₂ , HCl, (most solid, liquid, and nuclear rocket working fluids, air, and planetary atmospheres can be simulated)
Gas Contamination	Less than 0.1% of weight flow
Duration	Greater than 5 minutes at max. power. Over 60 minutes at 1/2 max. power.
Sample Locations	Three moveable inserter arms and two fixed holders
Control	Temperature, pressure, composition and flow rate can be changed during operation

2. Special Equipment and Instrumentation Available

High pressure chamber with two 5" and one 3" quartz view ports
Interchangeable sample arms
High temperature thermocouples, calorimeters, and enthalpy probe
Pyrometers, schlieren system
1.2 megawatt dc power supply 0-3000 v, 0-900 amp
200 gpm 500 psi cooling water system
Nozzle and specimen fixtures for direct attachment to the plasma head

3. Typical Applications

Materials testing under inert and controlled reactive atmosphere
Effect of gas composition and flow on heat flux
Temperature sensor development under hot flow conditions
Thermal shock testing
Simulation of re-entry heat-flux with controlled gas composition
Chemical reduction processes

Figure 1 - Schematic of HES Plasma Head and High Pressure Chamber

Three sample arms mounted in the chamber can be rotated sequentially into the jet to expose samples or instrumentation, or to scan the jet. Fixed holders are also available for experiment mounting. Two in-line quartz view ports provide means for optically viewing the experiments. A third view port is located above the sample at a 45-deg angle to permit viewing of the sample face. Figure 2 is a photograph of this system.

In studies where high-velocity gas streams are required, as might apply to the testing of nozzle materials, the plasma-generator head can be connected to a nozzle fixture as shown schematically in Figure 3. The main difference here, from the chamber-type tests as discussed above, is the parallel position of the test specimen with the gas stream. No secondary downstream pressurization is used; rather, the gas is expanded through a diffuser and exhausted to ambient. Figure 4 is a photograph of a nozzle attachment to the HES unit. Many other similar flow attachments are available and are retained for use in future programs.

The overall system is shown schematically in Figure 5. Power from a 2000-kva substation is supplied to the unit by a 1.2-Mw silicon-diode rectifier at an open-circuit voltage of 3000 v. A more detailed schematic of this electrical supply to the plasma-generator head is shown in Figure 6. Normal operating range is from 800 to 1800 v, at currents from 350 to 900 amps. A large percentage of the power is available for heating the gas; overall system efficiency is between 35 and 70%, depending on operating conditions. The rejected heat is removed by a 500-psi, 200-gpm cooling-water system. Storage facilities for up to a week's normal use of nitrogen, hydrogen, oxygen, carbon monoxide, hydrogen chloride, and carbon dioxide are available on site.

The control console, where gas composition, temperature, and pressure are set, is shown in Figure 7. For most purposes, gas temperature is determined by either making a heat balance on the system or by direct thermocouple measurement. The thermocouple reading is observed directly at the

Figure 2 - HES Plasma Head and Test Chamber

Figure 3 - Schematic of Nozzle Fixture Housing to HES Plasma Gas Generator

Figure 4 - HES Plasma Head and Nozzle Fixture

Figure 5 - Schematic of HES System

SWITCH S IS IN POSITION B FOR CONNECTIONS AS SHOWN ABOVE.

* WHEN SWITCH S IS IN POSITION A INSTALL COIL L IN SERIES WITH ARC.

Figure 6 - Schematic of HES Power Supply

Figure 7. - HES Control Console

control console to permit setting and variation of temperature during operation. All system and experimental data are continuously recorded by the instrumentation system shown in Figure 8.

Figures 9 through 15 show some of the typical specimens and equipment setups used in the HES. Figure 9 also shows a specimen assembly used to study the silver loss mechanism of silver-infiltrated tungsten. Figure 10 shows an unshielded silver-infiltrated-tungsten specimen being exposed in the HES. Figure 11 shows high-temperature tungsten-rhenium thermocouples ready for testing in the HES chamber. Figure 12 is a test-chamber setup used for testing ceramic-coated tube specimens as shown in Figure 13. The tube specimens were mounted 45 deg to the plasma gas stream so special optical temperature measurements could be performed through the test-chamber quartz windows. Figure 14 shows an uncooled nozzle and HES plasma head setup used to study nozzle throat materials. Figure 15 shows a fibrous-graphite nozzle-exit-cone specimen used in high-velocity-hydrogen flow studies. To overcome heat losses and enable independent control of specimen temperature up to 4000°R, a heating element was provided on the back side of the specimen. The HES setup used is the horizontal plasma head mount shown in Figure 4.

III. CONCLUSIONS

Table II lists typical HES applications and performances achieved. System operation limits indicated here are not necessarily upper limits but represent the extent to which system performance has been experimentally verified. During the past year, test durations were extended from the initial design maximum of 5 min to 1 hr. Achievement of this long operation requirement resulted from the development of a new and less expensive plasma electrode design. Present gaseous-flow operation is limited to subsonic, sonic, and supersonic (up to Mach 3.5).

The wide variety of programs conducted in the HES Facility has resulted in the development of special experimental hardware with unique capabilities available for use with the system. A partial list of applicable HES drawings

Figure 8 - HES Instrumentation Console

Figure 9 - Tungsten Specimen Test Assembly

Figure 10 - Silver Infiltrated Tungsten Specimen Exposed in HES Plasma Gas Flame

Figure 11 - Tungsten-Rhenium Thermocouple Installed in HES Pressure Chamber

Figure 12 - HES Chamber Set-Up for Testing Ceramic

Figure 13 - Ceramic-Coated Tube-Specimen

Figure 14 - HES Plasma Head and Uncooled Nozzle

Figure 15 - Fibrous Graphite Nozzle Specimen and Housing Assembly

TABLE 2

TYPICAL HES PROGRAMS AND PERFORMANCE ACHIEVED

Program Description	Gas	Temperature °F	Pressure (psig)	Mass Flow Rate (lb/min)	Materials Tested	Typical Test Time	Number of Tests	Test Type
1. Effect of solid motor gases on internal insulation	a) N ₂ only b) CO, CO ₂ , H ₂ , H ₂ O, N ₂ , HCl	6000	350-550	4 - 9	V-44, V-52 rubber, asbestos- and silica-phenolic	20 sec	23	Stagnation heating of 1" rod
2. Effect of solid motor gases on graphite	a) N ₂ only b) CO, CO ₂ , H ₂ , H ₂ O, N ₂ , HCl	6000	500	6	ATJ graphite	60 sec	3	Stagnation heating of cone
3. Performance of silver infiltrated tungsten	CO, CO ₂ , H ₂ , H ₂ O, N ₂	5000-8000	200-300	4 - 9	Silver infiltrated tungsten	60 sec	16	Stagnation heating of rod
4. Effect of temperature on silver infiltrated tungsten	N ₂	4500-8000	450	6 - 15	Wrought and silver infiltrated tungsten	60 to 120 sec	30	Stagnation heating of rod
5. Effect of oxidizing atmosphere on impregnated graphite	a) N ₂ b) CO, CO ₂ , H ₂ , H ₂ O, N ₂ c) H ₂ , H ₂ O, N ₂	5500-7000	450	6	ATJ, H205 Graphite and various impregnants	60 to 120 sec	15	Stagnation heating of cone
6. High temperature thermocouple development	a) N ₂ b) N ₂ , H ₂	3000-4500	450	2 - 9	Tungsten thermocouple	5 to 6 min	31	Hot gas source
7. Corrosion of carbon cloth reinforced phenolic	N ₂ , H ₂ O, H ₂	5800	450	6.0	Various types of carbon cloth phenolic	20 sec	11	Stagnation heating of cone/cylinder
8. Ablative plastic nozzle materials	N ₂ , H ₂ O, H ₂	6200	500	5.0	Various types of ablative plastics	25 sec	30	Blast-tube specimen
9. Malfunction sensor	N ₂ , H ₂ O, H ₂	5800	450	6.0	Rubber insulation with electrical grid for char sensing	25 sec	30	Stagnation heating of 3" dia flat plate
10. NERVA thermocouple calibration	H ₂ , N ₂	4000	275	2.5	High temperature thermocouple	60 sec	22	Hot gas source
11. Turbine blade	N ₂	2200	350	12	Transpiration-cooled turbine blade	40-60 sec	9	Hot gas source
12. Hot hydrogen tests	H ₂	2000-5000	200-400	2 - 5		10-60 sec	30	Hot gas source
13. MHD Generator	N ₂	7000	5	3.0	Test of novel construction technique for Hall mode MHD power generator	20-80 sec	10	Hot gas source
14. Carbide thermal shock	N ₂	6000	400	6.0	Various coated carbides	10-20 sec	37	Blast tube
15. Refractory coatings for high heat flux application	H ₂ + O ₂	5800	100	6	Various refractory coatings	5-15 sec	30	Stagnation heating of tube bundle
16. High power laser	N ₂ + CO ₂ + He					60 sec	56	Hot gas source
17. Infiltrated tungsten nozzle inserts	N ₂ + He	8000	450	3.5	Graphite, tungsten with various metal infiltrants	60 sec	41	Nozzle throat
18. AGCarb Nozzle Tests	H ₂	4200	200	1.2	AGCarb and graphite	10 min to 1 hour	157	Nozzle entrance and exit
19. AGCarb diffuser Test	H ₂	4200	200	1.2	AGCarb	10 min	13	Supersonic nozzle
20. Fluidic temperature sensor	H ₂	1200-2500	200	1.2	Temperature sensor	10 min	47	Hot gas source

is provided in Table III. The references listed herein report the results of some of the programs conducted and may be consulted for more detailed data for a particular application.

TABLE III

ASSEMBLY DRAWINGS APPLICABLE TO THE HES SYSTEM*

<u>Drawing Title</u>	<u>Aerojet Drawing No.</u>
1. HES Plasma Generator Assembly	T-408039
2. Cathode Assembly	380874
3. Anode Assembly	380885
4. Mix Chamber	1146977
5. Electrode Assembly, Water Cooled	1134202
6. Thermocouple, Immersion 90°-Tungsten with 5% Rhenium, Tungsten 26% Rhenium	1134450
7. Nozzle Tester, AG Carb	1136891
8. Pressure Checkout Specimen	1137591, 2, 3, & 1137803
9. Nozzle Tester Assembly (Mix Chamber)	1138087
10. Particle Collector	1138117
11. Nozzle Tester Assembly, Fluidic Temperature Sensor	1138068

*Subject drawings are to be found in the Aerojet Drawing File and represent only drawings that have been checked and released. Many unreleased sketch-type drawings of test fixtures and specimens are retained in the private file of the Aerophysics Laboratories.

REFERENCES

1. Lewis, W.J., Coatings for Advanced Thrust Chambers, NASA Lewis Research Center, Report No. NASA CR-72604, dtd. September 1969
2. Kotfila, R.J., Metal-Infiltrated Tungsten Rocket Nozzle Inserts for Multiple Firings, Wright-Patterson Air Force Base, Contract No. AF 33(615)-1599, dtd. January 1969
3. Radtke, R.P. and Swope, L.M., Advanced Composite Carbide Nozzles, Edwards Air Force Rocket Propulsion Laboratory, Report No. AFRPL-TR-68-143, dtd. August 1968
4. Hoff, R.G., Time Response Test of Thrust Chamber Thermocouples in Simulated Rocket Firing, Aerojet General Corporation, Report No. RN-TM-0426, dtd. April 1967.