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PROJECT STATUS REPORT

Department of Energy
Contract ET-78-C-03-2052
AC03-78ET12442
Design and Test of an Exhaust-Gas
Clean-Up System for Powerplants
Using High-Sulphur-Content Fuels

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23 January 1979

INTERNATIONAL POWER TECHNOLOGY, INC.

INTERNATIONAL POWER TECHNOLOGY, INC.

506 OAKMEAD PARKWAY • SUNNYVALE, CALIFORNIA • 94086 • USA • TELE: 408/737-2225 • TELEX: 352066 SUVL/ATT:IPT

23 January 1979

Mr. John Facey
Division of Power Systems
Dept. of Energy
Washington, D.C. 20545

Dear Mr. Facey

Enclosed is the second progress report for Contract Number ET-78-C-03-2-52 entitled "Design and Test of an Exhaust Gas Clean-Up System for Powerplants using High Sulphur Content Fuels". This report includes the following sections:

- * Milestone Schedule and Status Report
- * Cost Plan by Work Breakdown Structure (WBS) Element
- * Description of each WBS element

The description of the WBS elements includes a narrative of work accomplished to date and work anticipated for the next reporting period.

Sincerely

Mark H. Waters
Program Manager

MILESTONE SCHEDULE and STATUS REPORT

The attached Form CR-535 shows the progress to date for each major element of the WBS. A description of each WBS element is given in a following section, and included is a narrative of work accomplished to date and work anticipated in the next reporting period.

Completion of the Data Acquisition System has slipped due to a delay in delivery from Hewlett Packard. Part of the labor costs allocated for this WBS element includes time for personnel to become familiar with the equipment and to integrate the system with the test set-up. Delivery is scheduled for early February and the system should be operational by March 1.

Completion of the test cell and the Fuel System has slipped as shown on the chart. This has turned out to be a significant undertaking (see following section) and is being paced by the three contractors supplying the plumbing, air conditioning and fuel tank. Completion of each is now scheduled for March 1, and no slippage in the completion of the Exhaust Gas Simulator is anticipated.

The other element underway is a pilot model of the two-stage deaeration system. This work is also described in the following section.

MILESTONE SCHEDULE AND STATUS REPORT

1. Contract Identification		2. Reporting Period		3. Contract Number																							
Design and Test of an Exhaust Gas Clean-Up System for Powerplants		1 Oct 78 through 1 Nov 78		ET-78-C-03-2052																							
4. Contractor (name, address)		5. Contract Start Date		6. Contract Completion Date																							
International Power Technology 506 Oakmead Pkwy Sunnyvale, California 94086		1 June 78*		30 June 80																							
7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. Fiscal Years and Months																								10. Percent Complete	
		FY 79												FY 80												a) Planned	b) Actual
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A			
1.1.1	Data Acquisition System																								90	75	
1.1.2	Exhaust Gas Simulator																								50	40	
1.1.2.1	Test Cell Completion																								100	70	
1.1.2.2	Fuel System																								90	75	
1.1.3	Condenser-Separator Apparatus																								0	0	
1.1.3.6	C-S Test Program																								0	0	
1.2.1	2-Stage Deaerator Apparatus																								5	5	
1.2.1.7	2-St. Deaerator Test Program																								0	0	
1.2.2	Integrated Test																								0	0	
1.2.3	Scaling and Costs																								0	0	
1.3	Final Report																								0	0	

11. Remarks

* Contract signed 29 Sept 78; the prior period from 1 June 78 is designated as a pre-contract period for cost accrual purposes.

12. Signature of Contractor's Project Manager and Date <i>Mark D. Wilson</i> 1/23/79	13. Signature of Government Technical Representative and Date <i>CITART 1</i>
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COST PLAN

The cost plan shown in chart 2 is a breakdown of costs into the major elements of the Work Breakdown Structure (WBS) (three digit level). Major sub-elements (four digit level) are also broken out when applicable to high light work which is currently underway.

COST PLAN

FORM APPROVED
OCT 20 20 11 11 11

1. Contract Identification Design and Test of an Exhaust Gas Clean-Up System for Powerplants Using High Sulphur Content Fuels															2. Contract Number ET-78-C-03-2-52												
3. Contractor (name, address) International Power Technology, Inc. 506 Oakmead Parkway Sunnyvale, Ca. 94086															4. Contract Start Date * 1 June 78												
															5. Contract Completion Date 1 July 80												
6. Identification Number	7. Reporting Category (e.g., contract line item or work breakdown structure element)	8. Planned Prior Fiscal Years	9. Actual Prior Fiscal Years	10. Planned Current Fiscal Year												Total	11. Planned Future Fiscal Years					12. Planned Subsequent Fiscal Years to Completion	13. Total Planned Cost (Columns 8, 10, 11, and 12)				
				O	N	D	J	F	M	A	M	J	J	A	S		a	b	c	d	e						
1.1.1	DATA ACQUISITION SYSTEM																										
	Direct Labor			1082	2163	1622	1082									5949	0										5949
1.1.2	EXHAUST GAS SIMULATOR																										
	Direct Material			11256	2024	8024	16274	24324	9924	7293	993					80162	0										80162
	Direct Labor			9733	8651	8652	8651	9733	8111	5948	4326					63806	0										63806
	Consultants			150	300	2774	300	1112	225	150	75					5086	0										5086
1.1.3	CONDENSER-SEPARATOR																										
	Direct Material									2431	331	1424	1598	1198		6982	0										6982
	Direct Labor									1622	3785	6489	10815	10815	9193	42719	0										42719
	Consultants									75	150	225	300	3757	150	4657	0										4657
1.2.1	2-STAGE GENERATOR																										
	Direct Material													399	1597	1996	2358										4354
	Direct Labor					541	1082	1082	1092	1082				1622	9733	16224	50575										66799
	Consultants							371						150	225	746	4073										4919
1.2.2	INTEGRATED TEST																										
1.2.3	SCALING & COSTS															1157	1157	15578									16735
1.3	FINAL REPORT																										
	DIRECT OVERHEAD			7078	7078	7078	7078	7078	7078	7078	7078	7078	7078	7078	7078	84941	48483										153424
	G&A			5421	5421	5421	5421	5421	5421	5421	5421	5421	5421	5421	5421	65052	48789										112841
	TRAVEL			1500						1143						1226	3869	2905									6774
14. Total																383344	239961										

DESCRIPTION OF WBS ELEMENTS

Data Acquisition System (1.1.1.)

With the primary constraint of limited manpower, it is mandatory that a modern and efficient data acquisition system be used with this and other experimental programs conducted by IPT. The objective is to have a system which can assimilate data from many channels in digital form, compute the parameters of interest while the experiment is on-going, and display the results both on a scope and with a printer-plotter.

The system which has been selected is a Hewlett Packard System which operates as shown in the block diagram below.

- (1) Sequencer (40 channels)
- (2) Analog to Digital Converter
- (3) Programmable Digital Calculator
- (4) Data Recorder (printer/plotter)
- (5) Real Time Test Monitor (CRT)

This system will be delivered in early February and will be operational by 1 March 1979.

FIGURE 1, TEST ARRANGEMENT

Exhaust Gas Simulator (1.1.2.)

A hot exhaust gas containing a regulated amount of SO_2 gas will be generated by the Exhaust Gas Simulator (EGS). The required mechanical equipment for the EGS includes the following:

- a Y T65-T-1 turboshaft engine and support system
- an engine inlet venturi section for airflow measurement
- hot exhaust transition ducting
- a regenerative heat exchanger
- a water spray mixing rig
- an SO_2 gas mixing rig

A schematic layout of the EGS is shown in Figure 1.

The turboshaft engine is in hand, and the remaining equipment will be fabricated in-house. The design work is underway and the fabrication work will begin in February. The largest lead-time item is the regenerative heat exchanger, and it is planned to conduct initial tests without this unit and integrate it into the system once it is completed.

Besides the equipment described above, the EGS includes several other sub-systems as elements of the total unit. These include the test cell, the fuel system and the water systems.

Test Cell (1.1.2.1.)

The test cell design has been designed and is being constructed in stages. Figure 2 is a plan and elevation drawing of the cell. A double wall design with insulation is necessary for noise purposes, and double doors for personnel access are required to the same reason. This has been completed. Remaining work includes the construction and installation of the equipment access door, viewing portal, instrumentation and control panel, bypass engine exhaust duct through the ceiling, and fresh air access and exhaust ducts through the ceiling. The latter unit requires an air exhaust fan to meet the air circulation requirements in the test cell.

FIGURE 2a, TEST CELL (ELEVATION VIEW)

FIGURE 2b, TEST CELL (PLAN VIEW)

Fuel System (1.1.2.2.)

The fuel system for supply of fuel to the turboshaft engine includes a 1000 gallon fuel tank, a fuel pump and fuel lines and valves. An elevation drawing of the system is shown in figure 3. The installation of the fuel tank requires approval of the City of Sunnyvale. This approval will be granted only after an evaluation by the Bay Area Air Pollution Control District (BAAPCD). This evaluation is underway.

Air Inlet System (1.1.2.3.)

The air supply ducts shown in figure 2 was designed to provide sufficient air for the operation of the Y T65-T-1 turboshaft engine and test cell cooling.

The objectives in the design of this system are as follows:

- to remove heat from the test cell during the test as well as during the engine soak-down period
- to perform scavenging to prevent the possible build-up of combustibile vapors in the test cell
- to conduct emergency purging to remove fumes in case of fuel spill. The equipment access gate can also be used to supplement emergency purging.
- to maintain adequate acoustical privacy.

The engine itself will require approximately two-thirds of the air supply, and the amount will be measured in a venturi section ahead of the engine. This section has been designed and is shown in figure 4.

Figure 2 shows large baffles at both the air inlet and exhaust from the cell. These are necessary for acoustic reasons. The system is designed to create only a slight vacuum (less than 0.5 inches of water) in the test cell.

Water System (1.1.2.4.)

There will be extensive use of water during the testing. Besides water to the regenerative heat exchanger, water will

FIGURE 3, FUEL SYSTEM

FIGURE 4, VENTURI FLOW METER

be supplied to the dynamometer in order to absorb torque and provide cooling. In addition, water will be used in the shower heads in the condenser/separator. To satisfy these requirements, a 1 1/2 inch supply line will be run to the test cell; and drains to a sump will be installed to handle occasional spill and dynamometer discharge. Water will be pumped from the sump to the closest sewer connections through overhead lines.

To complete the water system for the test, three storage tanks will be installed outside the test cell. These tanks will be portable pools 8-10 feet in diameter and 4-5 feet deep. One will be a source of water for the dynamometer in case the supply through the 1 1/2 inch line is insufficient to supply all the requirements for the experiment. Figure 5 is a schematic drawing of the water supply and loop for the dynamometer. Provision is made for direct supply and discharge to the drain or for closed loop operation to the cooling storage water tank. As an alternative a forced air evaporation cooling tower can replace the tank. This alternative is now under evaluation.

The other major source of water use in the experiment will be in the condenser/separator. Figure 6 shows a schematic of the condenser/separator with direct supply of water to the spray nozzles at the top of the towers and discharge to a tank which will serve as both a cooling and a settling pond.

Remaining Elements in the EGS

The remaining sub-parts of the EGS are the hot exhaust ducting (1.1.2.5.), the regenerative heat exchanger (1.1.2.6.), and the mixing rig for water and steam (1.1.2.7.) and the mixing rig for the SO₂ gas (1.1.2.8.). Refer to figure 1 for the layout of these units within the EGS. Detailed design work on these units is just beginning, and of them the regenerative heat exchanger is the longest lead time item as mentioned earlier.

To assist in the design and construction of the regenerative heat exchanger, Mr. J. L. Boyen, a consulting engineer has been retained. Requirements for this unit have been defined, and a preliminary design of this unit will be completed in the next reporting period.

FIGURE 5, DYNAMOMETER WATER SYSTEM

TEST CELL

C/S - CONDENSER/SEPERATOR

FIGURE 6, CONDENSER/SEPERATOR
WATER SYSTEM

Instrumentation

Although instrumentation is broken out in the original WBS as a sub-system in the EGS, the condenser/separator and the deaerator, it is highlighted here as a major system since the equipment in question applies to all three major elements of the test apparatus.

The preparation of test instrumentation is closely coupled with the chosen data acquisition system, i.e., Hewlett Packard data acquisition system (H-P system). All thermocouples can be directly connected to the H-P system for fast scanning. The input analog signals will be digitized and recorded in desired temperature units. For pressures, a 48-channel Scanivalve pressure measuring system will be used to scan and record absolute pressure at various locations of the test stand.

The Scanivalve system was specifically designed to permit the rapid acquisition of measured pressures. This is accomplished by selectively switching the various pressure connections from the test stand by means of using a pneumatic selector switch to a common pressure transducer. This is not only economical in cost but also provides more dependable data because there is only one pressure transducer to calibrate.

An additional differential pressure transducer will be used to measure the airflow at the venturi flow meter. This transducer will be directly connected to an independent input channel of the H-P system.

A special purging technique will be required to measure steam pressures with the Scanivalve system so that condensed steam will not impair the data accuracy or cause corrosion problems. Several methods have been studied, however, the selection of a method to be used in the final testing will depend on the result of preliminary bench tests. The planning of preliminary bench tests is currently in progress.

Besides pressures and temperatures, the most significant data measured during testing will be concentrations of sulphur dioxide (SO_2) in the gas stream at various locations of the exhaust gas cleaning process. A Thermo Electron (TECO) Model 43 SO_2 analyzer in connection with their Model 900 heated dilution sample conditioner will be used to measure SO_2 concentration in the gas stream. The working principle of TECO Model 43 is to use pulsating ultraviolet light passing through a narrow-band filter to excite SO_2 molecules in a sample chamber. As these molecules return to the ground state they emit a characteristic fluorescence with intensity linearly proportional to the concentration of SO_2 molecules in the sampled gas. TECO Model 43 is a precision device which can measure only up to 50 ppm. However, the TECO Model 900 can provide a dilution ratio of up to 100 to 1. The combination of the two (2) devices will provide us precision as well as range.

Condenser/Separator 1.1.3.

The apparatus for the contact type condenser/separator will consist of two towers as shown in figure 7 (refer to figures 1 and 6 for integration of the condenser/separator into the total system). Each tower₂ will have a rectangular cross section of approximately 3 ft² to match the flow rate from the T65 engine. The height will be nominally 8 feet. Part of the project will be to vary these dimensions to determine optimum geometry for given test conditions. Water will be injected from the top of each tower and rows of baffles (like the fills in a cooling tower design) will be located along the length of each tower to promote mixing. The fills will be staggered so that there is no optical path from top to bottom through each tower.

Gas mixture from the EGS will be injected at the top of the first tower and the water vapor in this mixture will condense as mixing with the water spray takes place along the vertical drop through the tower. Water with SO₂ and other exhaust products in solution will collect in the basin at the bottom of the tower. The remaining exhaust gases will pass into the bottom of the second tower. A screen between the two towers will trap air-bound water droplets.

Fills are located in the second tower as in the first, and water spray from the top continues to mix with the exhaust gas as it rises through this second tower. Again, the water with SO₂ and other exhaust products in solution will collect in a² basin at the bottom of the tower. The water from both basins will be drawn off to maintain the depth in the basin approximately constant.

Detailed design work of this unit will begin during the next reporting period (see Milestone Schedule).

FIGURE 7 CONCEPT FOR CONTACT-TYPE CONDENSER-SEPARATOR

Two-Stage Deaerator (1.2.1.)

The apparatus for the 2-staged deaerator are shown in figure 8. Although the flow rate through the system will be a test variable, the equipment will be nominally sized for a water flow rate of 0.55 pps. This is anticipation of closed loop operation with the exhaust gas simulator and the condenser/separator. Key features of the components are as follows:

Pump A pressurizes the water from the condenser to a pressure of approximately 5 psig.

Hot water heater B raises the water temperature to approximately 220°F--just below the water boiling temperature at 5 psig.

Insulated tank C provides for the first stage of deaeration--all exhaust products are now in vapor form and pass through a dome at the top of the tank. Provision is made to bubble nitrogen gas into the bottom of this tank. This will serve a dual purpose: 1) to promote stirring to reduce the necessary residence time and thus the volume of tank C; 2) to reduce the partial pressure of water vapor in the dome of the tank and thus control the amount of water vapor passing into the second stage.

Porous screen D promotes formation of water droplets which are eliminated by gravitational dripping before the gas vapor mixture is vented.

Regulator valve E drops the pressure to slightly above ambient (1/2 to 1 psig depending on the depth of water in the second stage deaerator tank).

Second stage deaeration tank F--exhaust product vapors are forced down through an internal cylinder open at the bottom and bubble up to the surface. SO₂ and H₂S ← will be completely absorbed (a design objective), but the other products will only be partially absorbed. The remaining vapors at the surface will escape to the atmosphere.

Heat exchanger G maintains the water temperature at a specified level (there will be a variation of approximately 10°F with water depth in the tank).

Chemical control tank H provides for pH control of the recycled water. Blowdown is provided to remove precipitated salts.

FIGURE 8 .- BLOCK DIAGRAM OF PROPOSED TWO-STAGE DEAERATION SYSTEM.

For open loop operation, SO₂ from a high pressure bottle will be bubbled into the makeup water after pump A to give the proper concentration of SO₂ in solution. For closed loop operation, the water with SO₂ in solution will come directly from the condenser/separator.

Although the build up of test apparatus and testing is scheduled for phase 2 of this program, a small scale pilot experiment is scheduled in phase 1 (see Milestone Chart). The objective of the experiment is to batch simulate the two-stage deaeration process.

The apparatus for the experiment is shown in figure 9. Sulphur dioxide (SO₂) in water is highly temperature dependent and thus is readily absorbed in cold water immediately forming sulphurous acid according to the reaction:

Elevating the water/sulphurous acid temperature to 40°C reverses the preceding reaction causing most of the SO₂ gas to escape from the solution.

This temperature dependence is the basis for the IPT two-stage deaerator concept, and the following experimental steps outline a method to verify the concept and to provide useful data for the design and operation of the large scale unit which will be built and tested in phase 2.

- (1) Heat and air agitate a weak sulphurous acid solution over a carefully controlled temperature range of 20° to 95°C (equivalent to a weak exhaust gas scrubber solution) causing most of the SO₂ to gasify, along with a limited amount of water vapor which is recondensed in the water condenser back into the weak SO₂ feed solution flask.
- (2) Redissolve the SO₂ gas in cold water in the SO₂ concentrating flask; cold water has a large SO₂ absorption capacity as seen in figure 2.
- (3) Carefully monitor the solution temperatures (thermocouple probes) and solution SO₂ (H₂SO₃) concentrations (concentration/conductivity probes) vs time in both the weak SO₂ supply flask and concentrated SO₂ receiver flasks to yield flow and absorption rates for the system.
- (4) Concurrently monitor gas flow from feed to receiver flasks as well as SO₂ content in exhaust gas from the receiver flask vent.

The above steps will enable IPT to determine gas flow rates and solution concentration rates as well as concentration of SO₂ exhaust (if any) from the cold water SO₂ concentrator flask. The apparatus for experiment has been assembled, and initial tests will be conducted in the next reporting period.

FIGURE 9 IPT EXPERIMENTAL APPARATUS FOR CONCENTRATING SULFUR DIOXIDE IN WATER

Integrated Test (1.2.2.)

As a result of the parametric testing with both the condenser/separator and the 2-stage deaerator, a baseline configuration will be established. In phase 2 (see Milestone Chart) necessary modifications will be made to integrate the two systems together along with the exhaust gas simulator to provide a complete closed loop test. The apparatus and instrumentation will be essentially unchanged from that in the completed parametric tests. Figure 10 is a block diagram for closed loop operation.

FIGURE 10 BOTTOMING CYCLE CLOSED LOOP OPERATION

Scaling and Costs

It is anticipated that there will be sufficient information from this experimental program to scale the size of both the condenser/separator and the 2-stage deaerator to match the flow rates of full scale stationary powerplants as large as 100 MW. In addition, an estimate will be made for both capital costs and operating costs for the system. Recommendations will be made concerning continued research and/or pilot plant demonstration projects.

Although this work is scheduled for later in the program, cost data for this type of equipment is being collected.