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FINAL REPORT

OF

IMPACT REACTIVITY OF MATERIALS AT VERY HIGH OXYGEN PRESSURE

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812
(CONTRACT NO. NAS8-35135)

May 19, 1983

PREPARED BY

SCIENTIFIC SERVICES, INC.

500 WYNN DRIVE ◣ SUITE 508 ◣ HUNTSVILLE, ALABAMA 35805 ◣ (205) 837-9731

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H. W. Connor, P.E.; J. G. Minchey; Roy Crowder, Ph.D.; Rod Davidson, Ph.D.
SCIENTIFIC SERVICES, INC.
500 WYNN DRIVE SUITE 508
HUNTSVILLE, ALABAMA 35805

ABSTRACT

Scientific Services, Inc., under Contract NAS8-35135, evaluated the requirements for impact testing of materials in an oxygen atmosphere at pressures from 82.7 MPa (12,000 psi) to 172 MPa (25,000 psi). The current NASA/MSFC impact tester system was evaluated for potential pressure increases from the present 69 MPa (10,000 psi) to 82.7 MPa (12,000 psi). The low pressure oxygen and nitrogen systems, the impact tower, the impact test cell, and the high pressure oxygen system were evaluated individually. Although the structural integrity of the impact test cell and the compressor were sufficient for operation at 82.7 MPa (12,000 psi), recent studies revealed possible material incompatibility at that pressure and above.

Scientific Services adopted the philosophy that if a component should be replaced for 82.7 MPa (12,000 psi) operation the replacement should meet the final objectives of 172 MPa (25,000 psi). Recommended changes in the system include; use of Monel 400 for pressures above 82.7 MPa (12,000 psi); use of bellows to replace the seal in the impact tester; use of a sapphire window attached to a fiber optic for event sensing; and use of a three diaphragm compressor. Redesign of the system will also enable incorporation of updated electronic controls and data handling, and improved remote control operation.

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I. INTRODUCTION

This study was initiated to investigate the requirements for increasing the operating pressure and temperature of the ABMA configured (1, 2, 3, 4, 5) LOX/GOX 69 MPa (10,000 psi) materials mechanical impact tester currently in use at the Marshall Space Flight Center (MSFC) (Figure 1). This investigation will consider the additional refinements necessary to increase the pressure to 172 MPa (25,000 psi) and 400° C, either incrementally or by one step.

Oxygen reactions with materials generally increase with pressure and can be self igniting and violent under certain conditions. To qualify materials as satisfactory for use under programmed gaseous and liquid oxygen conditions, the materials must be tested at elevated pressures and temperatures. Maximum National Aeronautics and Space Administration (NASA) propulsion systems operating pressures have been in the 55.2 MPa (8,000 psi) range. With the planned utilization of liquid and gaseous oxygen at pressures in the 103 MPa (15,000 psi) range in advanced propulsion systems, materials compatibility data in the high pressure environment is critical to the risk evaluation and design decisions in propulsion technology. The reactivity of materials at increased oxygen pressures cannot adequately or safely be projected from test results at lower pressures.

Acceptance test methods for materials in an oxygen environment are essentially in what could be called the third generation. The ABMA dropweight tester, originated in the 1940's and utilized in the 1950's, was refined and standardized in the 1960's resulting in the issuance of MSFC-SPEC-106B and the similar ASTM 02512-66T.

Advanced engine technologies proposed for the 1970's required higher oxygen pressures and the resultant second generation impact testers to qualify candidate materials for oxygen service at pressures

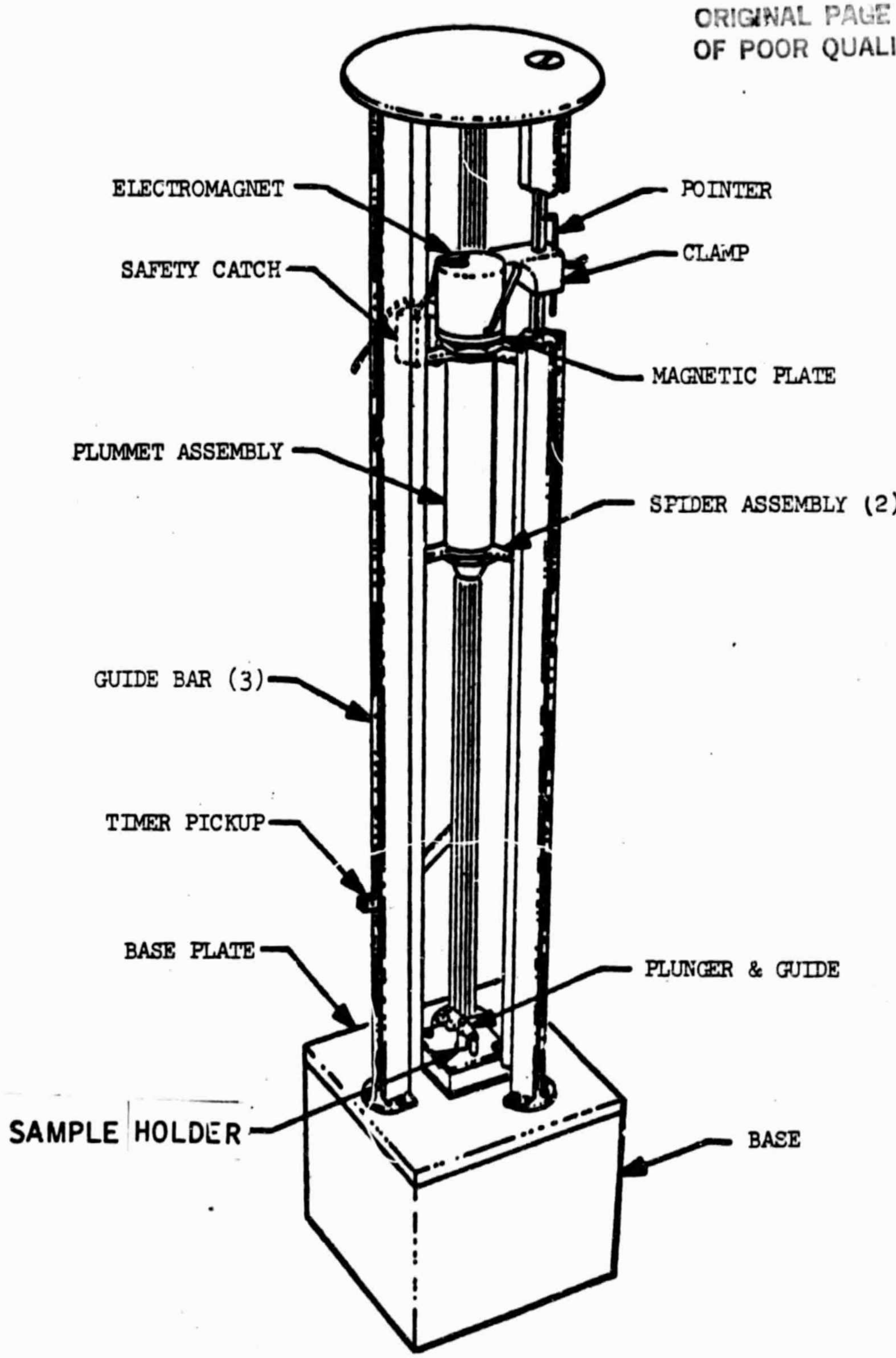

Figure 1. Impact Tester

to 69 MPa (10,000 psi). Two different 69 MPa (10,000 psi) mechanical impact testers similar to the ABMA-MSFC design were developed by the Johnson Space Center (JSC), White Sands Test Facility (WSTF) and by MSFC/Rockwell International, Rocketdyne Division. The MSFC/Rockwell developed mechanical impact tester is being used at MSFC. Systems to evaluate the compatibility of materials in LOX and GOX in the 82.7 MPa (12,000 psi) to 172 MPa (25,000 psi) range could be considered the third generation of testers.

A mechanical impact tester at WSTF in Las Cruces, N.M., was designed for use at 138 MPa (20,000 psi), but is not routinely used at that level. It differs significantly in design and operation from the MSFC/Rocketdyne tester at MSFC. There is also a pneumatic impact tester at WSTF that is operated routinely at 82.7 MPa (12,000 psi). There are other approaches to oxygen compatibility in development such as frictional rubbing and particle impact at WSTF and laser induced combustion at The National Bureau of Standards.

Marshall Space Flight Center issued contract NAS8-35135 to Scientific Services, Inc., (SSI) to evaluate the possibility of modifying the present MSFC impact tester for operation at 82.7 MPa (12,000 psi), to conduct literature and engineering studies to determine the requirements for the design of an impact tester to operate at 82.7 MPa (12,000 psi), and to determine the extent of currently available hardware for working up to the 172 MPa (25,000 psi) range.

A comprehensive literature survey was conducted. Although published material was available on the general subject of high-pressure technology, most of it concerned research with solids, liquids, and gases other than oxygen. Only a few articles addressed pressures above 69 MPa (10,000 psi) or gave information directly related to high pressure oxygen reactions.

The primary sources containing information on oxygen and its associated materials and components are Schwinghamer and Key (1974), Bransford, Bryan, Frye, and Stohler (1980), Hust and Clark (1974), White and Ward (1966), Baum, Goobich, and Trainer (1962), Attwood and Allen (1971), Dean (1961), Guter (1967), Kinzey (1970), Kirschfeld (1961), (1965), (1967), (1968), NASA-MSC-02681 (1972), Bond (NASA-JSC, in publication), and Johnston (NASA-JSC, in publication). These are listed in the appendix. Other articles which provide helpful information about materials, equipment, instrumentation, experimental techniques, and safety procedures are also listed.

One of the initial objectives of SSI's study was to assess the current high pressure 69 MPa (10,000 psi) oxygen impact test equipment at MSFC to determine the extent of modifications necessary to increase test pressure limits to 82.7 MPa (12,000 psi).

SSI adopted the following modification philosophy. If any of the present MSFC impact tester system requires modification or replacement, the replacement or modification should have the capability of reaching the ultimate goal of impact testing at 172 MPa (25,000 psi). Obviously, initial cost would be a consideration; however, the cost of maintaining one system at 82.7 MPa (12,000 psi), another at 103 MPa (15,000 psi), and others in increments up to 172 MPa (25,000 psi) could be substantially more.

II. The Current MSFC Impact Tester System

The philosophy of this study has been directed towards modifications essential for operation in the 82.7 MPa-172 MPa (12,000-25,000 psi) pressure range and temperatures from cryogenic to 400° C This study concept was not intended or directed in any way towards changing or modifying the current concept for impact testing of materials.

The initial objective was to evaluate the present MSFC Impact Tester System (Figure 1) to determine which portions, if any, could be used at 82.7 MPa (12,000 psi). The system was divided into its' various operational groups and each one evaluated separately.

HIGH PRESSURE OXYGEN SOURCE

The current impact tester high pressure oxygen source is an Aminco-Corblin (which is now Superpressure, Inc.) motor driven, two-stage diaphragm type compressor, catalog number 46-13426. It is designed to boost pressure to 138 MPa (20,000 psi) at a 14 to 1 maximum compression ratio. Compressor parts in contact with the gaseous oxygen are made of different materials. The upper head plates are A-286 alloy; the check valves are 316 stainless steel, and the two diaphragms are 302 stainless steel. The compressor is capable of furnishing 0.0906 cubic meters (3.25 SCF) per hour at a suction pressure of 3.45 MPa (500 psi).

The main disadvantages of this compressor are the compressor parts with minimum compatibility in gaseous oxygen environment at high pressure and the possible diaphragm rupture that cannot be "spotted" from the control room. A diaphragm rupture creates major problems when pulsing fluid enters the oxygen lines because of delay due to necessary tear-down, cleaning, and reassembly. White Sands Test Facility has used the same type compressor on a routine basis at pressures above MPa (10,000 psi) and indicates a diaphragm life of approximately 50 hours when pumping at high pressure.

Superpressure, Inc., the current manufacturer of this compressor, was contacted for information and philosophy on the design of these pumps for high pressure operation in the oxygen environment.

Superpressure, Incorporated (Mr. Kevin J. Lyons) responded as follows--

"I have heard of our compressors being used at 30,000 psi with oxygen. However, because of the nature of this application we make no guarantees as to safety or suitability. We sell the compressors preliminarily cleaned, and the ultimate responsibility lies with the user.

I am not sure what operating pressure is intended. I note in the file a reference that a special material would probably be needed above 15,000 psi.

This brings me to the main point of this correspondence. We have always had problems maintaining a seal above 22-25,000 with a Viton O-ring. Also with the Monel diaphragm used in this particular compressor we found the (soft) Monel would dimple (begin to extrude) into the gas and pulsing fluid ports.

In view of these facts, I advised the shop to set the limiter at 22,000 psi, i.e., set the compressor up for a maximum operating pressure of 20,000 psi. Also, to overcome the diaphragm problem we used a backup diaphragm of 302 SS (WSTF is using brass.). This is commonly done and will be a considerable benefit in terms of diaphragm life. The user should be aware of this in case he ever changes diaphragms. The diaphragms are stamped "SS" or "M" (as applicable) at the periphery.

I hope these modifications do not present the user a problem. They are definitely advisable.

If there is a problem, please get in touch."

As noted above there are solutions to problems. Both WSTF and JSC were pleased with support obtained from Superpressure, Incorporated personnel.

Discussions with two manufacturers on the advisability of modifying the current MSFC compressors evoked very little interest. Both indicated they could manufacture a new compressor to the maximum pressure requirement cheaper than they could modify those on hand.

IMPACT TOWER AND ASSOCIATED ACCESSORIES

The current design of the tower and the plummet are considered adequate. During the refurbishment of the system the following modifications would prove beneficial.

- Consideration should be given to welded connections at some of the stress assembly points. This would contribute to a more rigid tower structure.
- Knife edge guides for the plummet in place of the rollers would aid free fall alinement on the striker pin.
- The impact tower and its associated accessories (4, 5) should be refurbished and brought up-to-date.
- The load-cell should be sent to the manufacturer for refurbishing.

IMPACT TEST CELL

The structural evaluation of the current test cell was based on using K-Monel material with a safety factor of 4 and an operation pressure of 69 MPa (10,000 psi).

Since Inconel 718 was used in lieu of K-Monel, a gain in safety factor was acquired. The maximum designed pressure in the oxygen cavity was 103 MPa (15,000 psi). Proof pressure of the impact test cell was accomplished at 103 MPa (15,000 psi). Based on WSTF unpublished reactivity data Monel 400 is a more compatible material for use at 69 MPa (10,000 psi) and greater, than is Inconel 718. The current design if refabricated using Monel would meet the minimum requirements for 82.7MPa (12,000 psi). Scientific Services recommends that the redesign be for Monel 400 for the ultimate pressure use to 172 MPa (25,000 psi). The following are items to be considered during the redesign.

- The base assembly should be redesigned to incorporate resistance heating.

- Attention needs to be given to changing the seal design at the tester interface to a compression type of the Bridgman design, of proper materials, before proceeding to 12,000 psi or greater.
- A redesign of the test cell sample holder volume, sensing probe locations, and event sensing should be addressed before attempting to operate at 12,000 psi or higher.
- The striker assembly should be redesigned using a bellows for a seal to eliminate the "stick-break" force-pressure problems at the striker.
- The redesign should incorporate an impact cell quick opening feature to speed-up testing.
- The redesign should incorporate a more effective event sensing capability.

The redesign should retain the many good features of the current design and be similar in function and characteristics. These design changes are addressed in detail later under specific design considerations.

LOW PRESSURE PNEUMATIC SYSTEMS

The current design of the pneumatic support systems, i.e., actuation cylinder pressure, pneumatic valve actuation, test cell balance pressure, and the liquid nitrogen cooling system are adequate. However, they should be replaced due to age and wear as well as reconfigured to adapt to the new system.

The replacement of these systems would permit incorporation of the following component improvements.

- The liquid nitrogen test cell cooling system should incorporate a means for throttling LN_2 flow so that the LN_2 may be used as a rapid source for changing test cell temperature.
- The nitrogen test cell balance pressure should be brought up-to-date with current servo capability.

HIGH PRESSURE FEED SYSTEM

Most of the current high pressure oxygen feed system is constructed of Monel. This includes the valves, fittings, and tubing. The exceptions are the surge tank and pressure gages. These are constructed of 316 stainless steel.

The Monel fittings in this system are from Autoclave Engineering, Incorporated and are constructed for a working pressure of 75.8 MPa (11,000 psi). As a minimum, for 82.7 MPa (12,000 psi) operation and greater, the replacement of this flow system with all oxygen wetted surfaces of 400 Monel and the elimination of the surge tank and the pressure gages from the new design will be required. There does not appear to be a sufficient cost savings to install 82.7 MPa (12,000) feed system and then replace it with higher pressure equipment later. Therefore, a system capable of 172 MPa (25,000 psi) should be used when the present 69 MPa (10,000 psi) rated system is replaced.

High pressure valves and fittings intended for oxygen service have orifice sizes for maximum flow of liquids and gases. Oxygen wetted parts are available from 400 Monel when special ordered.

The 59^{o} included angle coned and threaded tubing seal appears to be reliable in both cryogenic and elevated temperature application.

They are recommended for repetitive assembly and disassembly. However, the nature of the assembly would appear to require the replacement of the coned section when intended for high pressure due to its deterioration. Early users of these components with high pressure oxygen encountered leakage problems.

Safety weep holes are provided on both sides of all connections. This feature should be looked for when procuring these components.

Normally, valves and fittings will include the necessary tubing glands and collars unless otherwise requested.

OXYGEN SOURCE

The current MSFC mechanical impact tester source of oxygen is eleven (220 cu. ft., 2,200 psi) 1A cylinders manifolded together. This makes for a simple system; however, it is a very limited supply of oxygen when flow is directly off the cylinders for pressure testing since these cylinders are rated at 15.2 MPa (2,200 psi). Volume testing at high pressure will drop the cylinder pressure quite rapidly.

MSFC has oxygen tube trailers that are routinely charged to 15.2 MPa (2,200 psi). These tube trailers would be a larger volume source for oxygen testing and would furnish a volume in excess of ten times the current source. One of the existing 34.5 MPa (5,000 psi) tube trailers available to MSFC could be used to supply a greater volume. This same source can be used for a supply of oxygen to the suction side of a compressor intended for test pressures to 69, 82.7, 103, 138 and eventually to 172 MPa (10,000, 12,000, 15,000, 20,000, and 25,000 psi).

ITEMS TO BE REPLACED

Table I lists current installed units recommended for replacement. These items have been in use for over ten years. They are still serviceable, however, there have been instrumentation improvements that will extend testing capability.

Table II lists pneumatic enclosure hardware recommended for replacement. These enclosure systems will require rework and modification. The fittings for the oxygen system were designed for operation at 75.8 MPa (11,000 psi). The components of the system, although serviceable, have been used for over ten years. Replacement will permit staying current with progress in this very specialized area.

TABLE I

CURRENT INSTALLED UNITS TO BE REPLACED

1. Ballistics (High Frequency) Pressure Transducer, Model 207C(X) and 607C(X), Kistler Instrument Company (Replace)
2. Quartz Load Washer, Model 900A Series, Kistler Instrument Company (Replace)
3. Peak Meter Indicator, Model 538A, Kistler Instrument Company (Replace)
4. Dual Mode (Charge) Amplifier, Model 504D, Kistler Instrument Company (Replace)
5. Oscilloscope, Type RM565 (Serial No. 4524), Tektronix, Inc. (Replace)
6. Oscilloscope Camera System (Serial No. 9140), Tektronix, Inc. (Replace)
7. Dual Trace Amplifier, Type 3A6 Plug-In (Serial No. 13485 and 13488) Tektronix, Inc. (Replace)
8. OMNI Seals, Catalog 114, Aeroquip Corporation (Replace)
9. Constant Temperature Circulator, Manual #124A, Launda, Inc. (Replace)
10. Diaphragm Compressor, Aminco #46, Hand Operated or Motor Driven, American Instrument Company (Replace)
11. Digital Thermocouple Thermometer, Series 590, M1-1387, Digitec, United System Corporation (Replace)
12. Digital Voltmeter, Model 268, M1-1391, Digitec, United System Corporation (Replace)
13. Pressure Cell, DHF, (15-DHF-2), BLH Electronic, Inc. (Replace)
14. Power Supply, Dual 15 VDC, Model 528 (Replace)
15. Comparators, Catalog PDS-221, Burr-Brown Research Corporation (Replace)
16. Integrated Circuits, 3500 Series, Burr-Brown Research Corporation (Replace)

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TABLE II

PNEUMATIC ENCLOSURE HARDWARE

TO BE REPLACED

Item	Description	Material	Size	Working Pressure	Quantity
1.	Hand Valve, Autoclave No. 30VM-4071-OM	Monel	1/4 AE	12,000	5
2.	Pneumatic Valve, Autoclave No. 30VM-4071-OM	Monel	1/4 AE	12,000	5
3.	Pressure Gage Autoclave No. P483	316SS	1/4 AE	0 to 15,000	2
4.	Pressure Gage, Autoclave No. P480	316SS	1/4 AE	0 to 3,000	1
5.	Burst Diaphragm Holder Autoclave No. CS4600	Monel	1/4 AE	12,000	3
6.	Burst Disk	Monel	1/4 AE	15,000	2
7.	Burst Disk	Monel	1/4 AE	3,000	1
8.	Solenoid Valves, Barksdale No. 12453	Brass	3/8 NPT	150	6
9.	Miscellaneous High-Pressure Fittings				
	Autoclave No. CX4444-CROSS				4
	Autoclave No. CT4440-TEE				5
	Autoclave No. CL4400-ELBOWS				1
	Autoclave No. 60M42B8-ADAPTER				4
	Autoclave No. 60F4433-COUPLING				4
	Autoclave No. CP-40-PLUG				3
10.	Solenoid Valve, Marotta No. MV-100	SS	1/4 AN	3,000	2
11.	Filter, Aircraft Porous Media, Model No. AC4098-82Y2	SS	1/4 AN	3,000	1
12.	Pressure Transducer, BLH Electronics, Type DHF	SS	1/4 AN	1,000	1
13.	Pressure Transducer, BLH Electronics, Type DHF	SS	1/4 AN	1,000	1
14.	Pressure Gage, Ashcroft No. 1279	SS	1/4 NPT	VAC-15	1
15.	Pressure Gage, Ashcroft No. 1279	SS	1/4 NPT	100	1
16.	Pressure Gage, Ashcroft No. 1279	SS	1/4 NPT	2,000	1
17.	Hand Valve, Control Component MV-6008	SS	1/2 NPT	6,000	1
18.	Regulator, Matheson No. 8-540	Brass	1/4 NPT	3,000	1

III. Material Selection

Hust and Clark (6) observed that a reaction in an oxygen system can only occur in the presence of a fuel, an oxidizer, and an ignition source. However, when a material or a component is selected or a system designed for oxygen service an awareness that the fluid can be the oxidizer, the material of the system a potential fuel, and ignition sources are ever present in many forms should always be a prime consideration.

The selection of materials and components for oxygen service should be premised on eliminating potential effects such as--

- The effects of contamination within a system.
- Eliminate ignition--select a material which is least likely to ignite under the operational conditions.
- Prevent continued reaction--select a material which tends to quench the reaction after ignition.
- Reduce the rate of reaction--select materials which react as slowly as possible after ignition to permit control of the reaction.
- Match the particular demands of an oxygen component with materials best satisfying these demands. (This assumes the existence of several types of compatibility and physical properties data for these materials.)

  For example, if a component is likely to be impacted but not likely to be in a high temperature environment, materials with a low impact sensitivity should be considered with secondary considerations for their ranking according to ignition temperature.
- Equipment problems contributed by design. For example the introduction of slow opening valves and heat sinks to reduce the probability of ignition by adiabatic compression.
- Increasing oxygen wetted surface areas to aid in the dispersion of generated heat.

METALS

Although the tensile strength, hardness, and modulus of elasticity of many metallic materials increase as the temperature drops, ductility and toughness decrease. In general, it is advisable to use a material below its "transition"[1] temperature because above this temperature it has lost much of its capability to absorb energy without rupture. Nickel, copper, aluminum and some of their alloys are a few of the materials that have increasing impact strength with decreasing temperature.

Clark's (7) study of thermal expansion at low temperatures of similar alloys and alloy conditions indicates that relatively large changes in composition are required for significant changes in thermal expansions, that heat treatment or heat conditioning has little effect except when there is a basic material structure changes, and that the thermal expansion at room temperature is a good indication of the dimensional change to be expected at low temperature.

The initial materials selection for fabrication of the mechanical impact tester high pressure system and its associated equipment was based on results from limited studies of the ignition of materials in moderate pressure oxygen environment. Early materials ignition studies were conducted in gaseous oxygen at 51.7 MPa (7,500 psi) by the Battelle Memorial Institute (8). Test results indicated that metal alloys with a high percentage of nickel have the highest resistance to ignition in moderate pressure oxygen.

Additional studies by Battelle Memorial Institute (9) indicated that 316 stainless steel and monel alloys were acceptable construction materials at gaseous oxygen pressures to 51.7 MPa (7,500 psi).

Stainless steel 316 and monel (10, 11) are commonly accepted as good engineering alloys for oxygen service. Most of the standard hardware and most of the standard equipment available is fabricated from them. Monel is less strong but sufficient where weight is not a restriction. It has a low oxidation rate.

MSFC conducted ignition studies (2) and found nickel base super alloys Rene' 41, Inco 625, and Inco 718, the nickel-copper

[1]In this case used to denote the arbitrarily defined temperature in a range where ductility changes rapidly with temperature.

alloys Narloy x and K-Monel. and the cobalt base super alloy HS188 all passed the impact sensitivity test at the test pressure of 69 MPa (10,000 psi) and the use temperature. Later limited ignition studies conducted in gaseous oxygen at 103 MPa (15,000 psi) by the White Sands Test Facility (WSTF) (11, 12) indicated Monel 400 was the most ignition resistant of the alloys tested. No documented test data appears to be available for higher pressures. Current technology has not ventured into the realm of extremely high pressure 172 MPa (25,000 psi) oxygen testing. This is an area for research and development. Table III lists the properties of Monel 400.

The choice of materials (6) for a high pressure oxygen mechanical impact tester system depends upon a number of interrelated factors:

- Temperature and pressure range of operation and the requirements for proof testing.
- Pressure and temperature cycling (fatigue life).
- Corrosion or erosion factors.
- The compatibility of the oxygen wetted surfaces in the environmental conditions to be encountered.

Only the best suited material should be used and stringent control requirements should prevail during procurement. There should never by any doubt about the identity and quality of the materials.

For the important parts, the parts containing high pressure oxygen wetted surfaces, a manufacturers' certificate of identity and quality should accompany the stock materials, forgings, and component parts. For cold worked billets of Monel 400 this is extremely difficult to acquire for small quantities. An alternative is to purchase two billets from the same run, one for testing and one for fabrication or verify status by non-destructive testing, proof pressure cycling, and proceed on a calculated risk basis.

Most metal manufacturers maintain a continuous watch on the quality of their materials by regular sampling and metallurgical examination. Therefore, using material on a calculated risk basis in a non-flight situation and in a research and development

TABLE III

PROPERTIES OF MONEL 400

Composition:

	Nominal
Carbon	0.12
Manganese	0.90
Iron	1.35
Sulphur	0.005
Silicon	0.15
Copper	31.5
Nickel + Cobalt	66.0

Physical Constants: (at 70°F)

Specific gravity	8.83
Density, lb/cu.in.	0.319
Melting range, °F	2370-2460
Modulus of elasticity, psi, in tension x 10^6	26.0
in torsion x 10^6	9.5
Curie temperature, °F	20-50
Specific heat, Btu/lb/°F	0.102
Thermal coef. expansion/°F (70-200°F) x 10^{-6}	7.7
Thermal conductivity, Btu/ft^2/in/hr/°F	151
Electrical resistivity, ohms/cir.mil./ft.	307

PROPERTIES

Table 1 – MECHANICAL PROPERTIES – Rod & Bar

	Annealed	Hot Finished*	Hot Finished**	Cold Drawn Stress-Relieved
Tensile strength, psi	70000-85000	75000-90000	80000-95000	84000-120000
Yield strength, psi (0.2%)	25000-40000	30000-50000	40000-65000	55000-100000
Elongation, % in 2"	50-35	45-30	45-30	35-22
Brinell hardness (3000 Kg)	110-140	130-170	140-185	160-225
Endurance Limit, psi (10^8 cycles)	33500	–	42000	37000

*Hot finished hexagons over 2-1/8 inches and angles.
**Hot finished except hexagons over 2-1/8 inches and angles.

Table 2 – IMPACT STRENGTH
(None of the specimens were completely fractured)

Temper	Impact Strength, ft. lbs. Izod	Charpy V-Notch
Hot rolled	100-120+	220
Forged	75-115	–
Cold drawn	75-115	150
Annealed	90-120+	215

Table 3 – MECHANICAL PROPERTIES – (Seamless) Tube & Pipe

Condition	Tensile Strength, psi	Yield Strength psi (0.2%)	Elongation % in 2"	Rockwell Hardness
Cold drawn, Annealed	70000-85000	25000-45000	50-35	B75 max.
Cold drawn, Stress Relief	85000-120000	55000-100000	35-15	B85-100
Heat exchanger, Annealed	70000-85000	28000-45000	50-35	B75 max.
No. 1 temper (annealed)	85000 max.	30000-45000	45-30	B73 max.
No. 2 temper (½ hard)	85000-105000	55000-80000	30-10	B75-97
No. 3 temper (hard)	110000-130000	90000-110000	10-3	B95-C27

Table 4 – CREEP STRENGTH

Temper	Temperature °F	Stress, psi to Produce a Creep Rate of 0.10% in 10,000 hrs.	1.0% in 10,000 hrs.
Hot Rolled	700	30000	40000
	800	14500	25500
	900	4000	13500
	1000	–	3000
Cold Drawn, Annealed 1500°F 3 hrs.	750	20000	30000
	800	15000	24000
	900	8000	16000
	1000	3500	9500
Cold Drawn (20%) stress relieved at 1000°F 8 hrs.	750	33000	45000
	800	12000	30000
	850	7000	21000
	900	3500	12000
	950	1400	5200
	1000	580	2100

Table 5 – MECHANICAL PROPERTIES – Sheet & Plate & Strip

Condition	Tensile Strength, psi	Yield Strength, psi	Elongation % in 2"	Rockwell Hardness
Plate, Hot Rolled, Annealed	70000-85000	28000-50000	50-35	B60-76
Hot Rolled, As-Rolled	75000-90000	40000-60000	45-30	B70-89
Sheet, Cold Rolled, Annealed	70000-85000	25000-45000	50-35	B73 max.
Hot Rolled, Annealed	65000-85000	25000-45000	50-35	B60 max.
Cold Rolled, Hard	100000-120000	90000-110000	15-2	B93 min.
Strip, Cold Rolled, Annealed	70000-85000	25000-45000	50-35	B68 max.
Cold Rolled, Spring Temper	100000-140000	90000-130000	15-2	B98 min.

Table 6 – LOW TEMPERATURE PROPERTIES

Condition	Temperature °F	Tensile Strength psi	Yield Strength psi (0.2%)	Elongation % in 2"	Reduction of Area %	Charpy Impact, ft. lbs. V-notch
Cold Drawn	Room	103800	93700	19.0	71.0	181
	–110	117450	100850	21.8	70.2	178
	Room*	103400	93300	17.3	72.5	171
Forged	–297	128250	91500	44.5	71.8	216
	–423	142000	96400	38.5	61.0	–
Annealed	70	78650	31300	51.5	75.0	189
	–297	115250	49500	49.5	73.9	184

*Cooled to and held at –110°F for several hours prior to testing at room temperature.

Table 7 – SHORT TIME HIGH TEMPERATURE PROPERTIES OF HOT-ROLLED MONEL* alloy 400

Temperature °F	Tensile Strength psi	Yield Strength psi (0.2%)	Elongation % in 2"	Modulus of Elasticity psi x 10^6
Room	79000	30000	48	26.8
600	75000	21500	50	25.6
800	63500	21000	50	24.8
1000	45500	20000	26	23.7
1200	26500	14500	36	22.6
1400	17500	11000	44	21.3
1600	9000	6500	52	18.3
1800	5000	2500	60	–

*Tests made by holding the specimen at temperature for ½ hour, then pulling it at a speed of 0.016 in. per minute through the yield point and from there to fracture at 0.026 in. per minute.

Table 8 – MECHANICAL PROPERTIES – Wire (Cold Drawn)
(For sizes from 0.032-0.250 inch diameter)

Condition	Tensile Strength, psi	Yield Strength psi (0.2%)	Elongation % in 2"
Annealed	70000-95000	30000-55000	45-25
No. 1 Temper	85000-100000	50000-75000	30-20
¼ Hard	95000-120000	65000-95000	25-15
½ Hard	110000-135000	85000-120000	15-8
¾ Hard	125000-150000	100000-135000	8-5
Hard-Spring	145000-180000	125000-170000	5-2

Table 9 – RUPTURE STRENGTH

Condition	Temperature °F	Stress, psi to Produce Rupture in 100 hrs.	1000 hrs.	10,000 hrs.
Cold Drawn, Annealed 1500°F 30 min.	700	72000	70000	–
	900	46000	42000	–
	1100	24000	17000	12000
Cold Drawn (20%), Stress-relieved at 1000°F/8 hrs.	700	70000	62000	56000
	800	54000	44000	34000
	850	47000	35000	23000
	900	38000	26000	17000
	950	30000	20000	13500
	1000	24000	15000	10000

Table 10 – TENSION IMPACT STRENGTH

	Tension Impact			Tensile Properties				
Temper	ft. lbs.	Elongation % in 3.54"	Reduction of Area %	Tensile Strength psi	Yield Strength psi (0.2%)	Elongation % in 2"	Reduction of Area %	Brinell Hardness 3000 Kg
Cold drawn	96*	15.0	63.7	97250	86650	27.0	66.4	199
Annealed	129*	29.5	68.0	78350	35350	44.0	65.9	123

*Specimens completely broken.

environment may be acceptable since adequate steps may be taken during the design stage to compensate for anticipated material inadequacies. Complete items, such as the compressor and the test cell, should have a test certification including capacity data.

SEALS

Material selection for high pressure oxygen environments must be compatible and perform the basic functions required for the specified conditions. Seal materials and seal configurations are available to meet the general design requirements.

Teflon

Plain teflon is compatible and the material of use for those applications where extremely low friction and chemical inertness are the most important factors. Teflon has a very low coefficient of friction (0.04). It has some definite disadvantages, not the least of which is the tendency to cold flow.

Glass Filled Teflon

Glass filled teflon is used when an inert material is needed in applications requiring good wear compatibility under extreme conditions of pressure and temperature. Wearing of the metal mating surfaces is to be expected due to the abrasive characteristics of the glass filler; therefore, a good surface finish is essential. Good metal surface finishes reduce seal wear. Wear is nearly proportional to the metal surface finish. Good metal surface finishes permit more areas of contact at the sealing surface which improves sealing ability.

Sealing at low temperatures is substantially more difficult because plastics become harder and do not readily flow onto the metal mating surfaces; thus, better finishes must be provided. For oxygen service a surface finish of 2-4 RMS is desirable for dynamic conditions. Static applications may be adquately handled by a surface finish of 8-12 RMS. This type of compatible seal material will be required for oxygen service.

Stick-Slip of Seals

Seals made from elastomer material show a sharp increase in friction as the pressure increases. Stick-slip may be described as the jerking motion that occurs on a dynamic surface during the transition from static to dynamic movement. Surface finishes should provide a slick, hard surface (50-62 Rockwell C) which reduces adhering between sealing surfaces, reducing dynamic force requirements.

The current MSFC mechanical impact tester has stick-slip on the striker pin of 9-16% of pressure (13) and this can be expected to increase dramatically with the additional increase in pressure. This is an area that must be addressed during the modification design. The implementation of a diaphragm or bellows for a seal at the striker pin appears to have several advantages and should be considered during design.

Pressure Activated Seals

Bridgman (14, 15) has stated the one development which permitted reaching extremely high pressures without leaks was his invention of the unsupported area seal, now called Bridgman seal.

This seal works on the principle that the fluid pressure acts on the sealing material to increase the force of the seal against the part.

The seal becomes more effective as the pressure increases. It does have a limit, however, and that is the point where the deformation of sealing material is extruded.

This seal design or a modified version of this design will be required for high pressure oxygen applications.

For leak free sealing a seal material must have a minimum surface load of approximately 25 pounds per square inch.

COMPRESSOR FLUIDS

In the event of a compressor disc rupture, pressurized oxygen comes in contact with the compressor fluids. Fomblin Y appears to offer the combined properties of being acceptable as a compressor fluid and of being non-reactive. Fomblin Y is a low molecular weight polymer with the structure of perfluorinated polyethers. Fomblin Y fluids were tested to NASA MSFC-SPEC 106B and passed the test. Fomblin Y-06 was non-reactive at pressures up to 10,000 psia as reported in a NASA WSTF report on August 27, 1980. Additional data on Fomblin Y is included in Appendix I.

IV. DESIGN CONSIDERATIONS

In the design or layout of a high pressure oxygen system each component should be considered as a high pressure vessel, whether it be a compressor, a fitting, a valve, a piece of tubing, or just a seal. In the initial layout problem areas should be considered and techniques developed to eliminate or maintain anticipated reactions to a minimum. Complicated designs tend to leave too much room for operation error. The maximum design working pressure should be premised on anticipated chemical reactions as well as the pressurizing oxygen and temperature. (8, 9, 14, 16)

This survey revealed that compressors and other high pressure equipment have been improved by use of new materials and advanced designs. High pressure equipment is available as standard catalogue items from several vendors and a few vendors offer modifications for specialized applications. Scientific Services recommends using standard catalog items to the maximum extent. Most of these pieces of equipment have been designed, fabricated, and installed to meet requirements as set forth by the American Society of Mechanical Engineers (ASME), the American Institute of Chemical Engineers (AICHE), the National Bureau of Standards (NBS), the U. S. Department of Defense, the National Aeronautics and Space Administration (NASA), and other recognized organizations.

Scientific Services contacted numerous vendors of compressed gas equipment as well as instrumentation and control manufacturers. Three high pressure vendors were ultimately selected as having sufficient experience, manufacturing capability, and design modification ability to respond to the requirements of the oxygen impact tester. Several vendors appeared qualified to supply control instrumentation off of the shelf and local Huntsville sources were found that could fabricate specialized items.

In the pressure ranges under consideration, the ASME Code (Section VIII, Division II) is of limited applicability. The basic concept of following good engineering practices and selecting the best materials is the best approach. This, plus good manufacturing and inspection procedures, can provide the basis for a good non-code design for this application. (14, 17)

D. E. Witkin (National Forge Company)(14) proposed that a safe, reasonable and good logical approach could consist of the following procedures of Section VIII, Division 2, Appendix 4 of the ASME Boiler and Pressure vessel code, modified to the following extent.

- That Sm be defined as Sy/1.5 where Sy is the yield strength.
- That Maximum Strain Energy (Maxwell/Von Mises) theory be used for combined stress calculations.
- That the following additional criteria be superimposed:

  (a) The maximum stress intensity at the bore of the vessel at design pressure be no greater than the yield strength; (b) the burst pressure to be more than 1.25 times the hydrostatic test pressure; and (c) the full plastic flow pressure to be more than 1.10 times the hydrostatic test pressure

The compressed oxygen for the impact tester should be viewed as three different systems, i.e., gaseous oxygen feeding the test cell cavity directly from the gaseous oxygen cylinder supply for relatively low pressure testing, the first stage of a two stage compressor system for pressures up to 34.5 MPa (5,000 psi), and the two stage compressor for extremely high pressure operation. During the design stage each of these systems should be assembled so individual operation may be selected. This concept was derived for ease in operation and to decrease the operating time on the high pressure compressor diaphragms due to problems anticipated in this area. The technology for the compressor design is available; however, delivery times can be expected to be 30 weeks or greater. These compressors are built to specific requirements and the material of construction is selected by the purchaser.

HIGH PRESSURE FLOW SYSTEM

The source of the high pressure oxygen for the mechanical impact tester is the compressor with its suction and discharge. Each of these basic systems will be reviewed.

The diaphragm compressor, the most contaminant free of the pressure buildup equipment is a combination of two systems, a hydraulic system and an oxygen gas compression system. A metal diaphragm group is the isolating component between these two systems. The oxygen gas compression system consists of flat metal diaphragms clamped between two precisely contoured concave cavities, and the gaseous oxygen inlet and outlet check valves. The hydraulic system includes an electric motor driven crankshaft which reciprocates a piston in the hydraulic fluid media. This positive displacement piston pulses the hydraulic fluid against the lower side of the diaphragm group causing it to sweep the cavity displacing the oxygen gas on the other side of the diaphragm, and discharging the oxygen gas through the discharge check valve to the high pressure manifold. (See Figure 2)

The oxygen wetted surfaces within this compressor are the diaphragm, the concave head, and the inlet and outlet check valves. The material considered most ignition resistent in high pressure; high temperature LOX/GOX is Monel 400; therefore, these components should be fabricated of this material. The hydraulic fluid for oxygen service is halocarbon although Johnson Space Center in Houston (18) (JSC) uses Fomblin Y-06. This material is batch tested for JSC (Hamilton-Standard) at WSTF. They have never had a mechanical reaction when batch tested. One batch failed when tested pneumatically. This batch was replaced. (This fluid is handled by Montedison Company, NY)

It is essential that the compressor be water cooled to protect the Monel 400 diaphragm and to assure the gaseous oxygen is pumped to the test cell at ambient conditions. Water cooling will assure a high pressure oxygen supply with a Delta of 2^{o} C.

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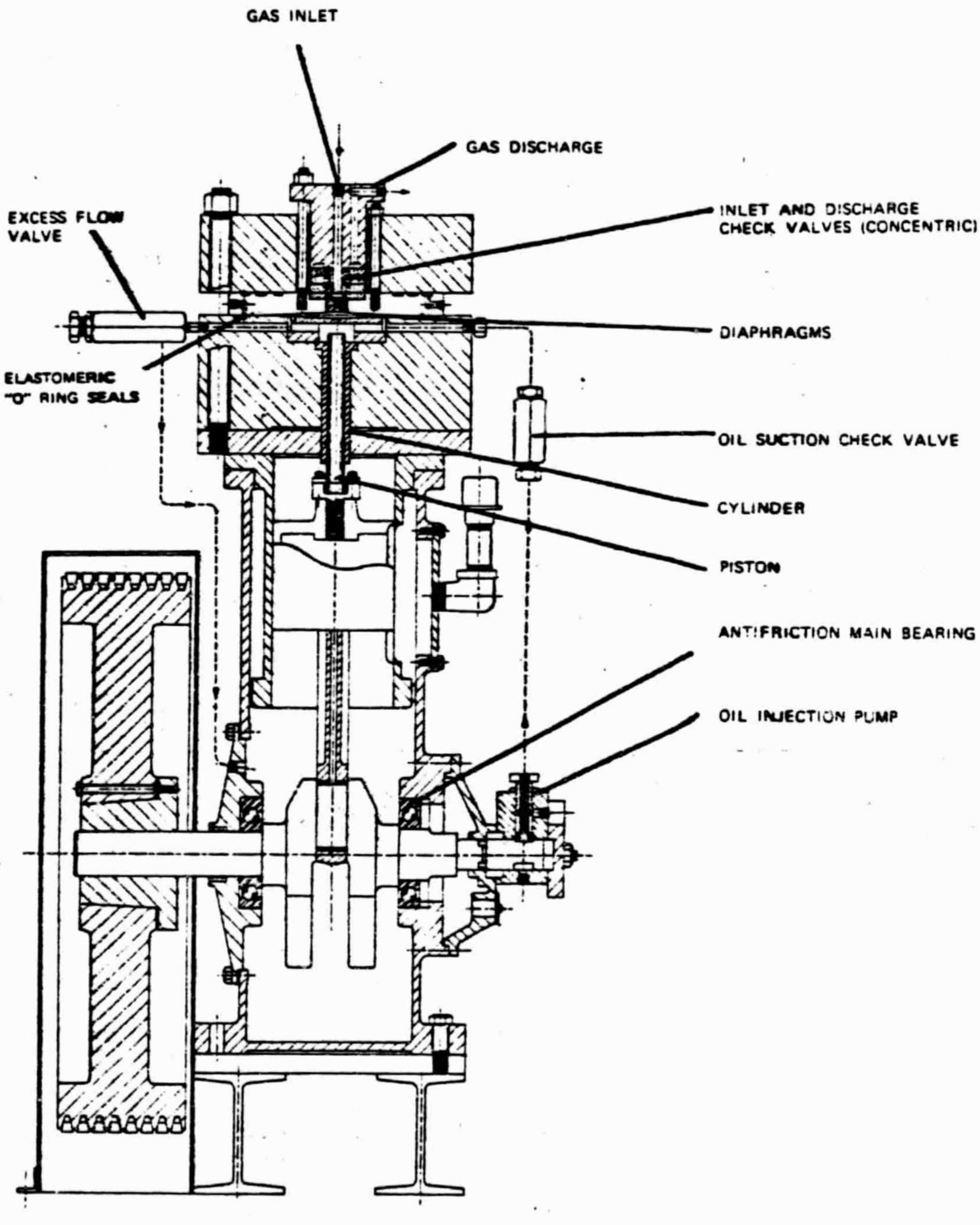

Figure 2. Diaphragm Compressor

Three diaphragm compreseor manufacturers were selected: (a) Superpressure, Incorporated; (b) Fluitron, and (c) Pressure Products Industries. These manufacturers will produce diaphragm compressors to special requirements on special order. There are others such as Harwood Engineering who will machine to special designs when they are submitted. For additional information on capabilities of compressors consult references (19, 20).

Superpressure, Incorporated, Pressure Products Industries, and Fluitron all indicate they can furnish diaphragm compressors which offer--

- Leak free design.
- Contamination free compression.
- Pressure to 30,000 psi.
- Flow rate from 1.75-12.5 CFM
- Corrosion resistant materials (All wetted parts from Monel 400.).
- Leak detection.

The three manufacturers indicated that they could supply complete systems incorporating the following.

- Aftercooler.
- Motor starter.
- Automatic "on/off" Control system.
- Automatic unloading system.
- Suction and discharge pressure sensing instrumentation.
- Flow Control Systems.
- Temperature and pressure switches.
- Oil level switch.

One manufacturer of diaphragm compressors, Pressure Products Industries, uses their patented bootstrap closure. At pressures of 66.7 MPa (10,000 psi) and higher, sealing of the compressor head assemblies becomesdifficult and high torque of the bolts is needed to accomplsish a good, tight seal of the diaphragm. The bootstrap closure solves this problem (see Figure 3). A force is generated in the bootstrap cavity (between 1 and 3) by hydraulic fluid pressure, which is greater than the loads generated during the compression cycle. This assures a leak tight seal assembly.

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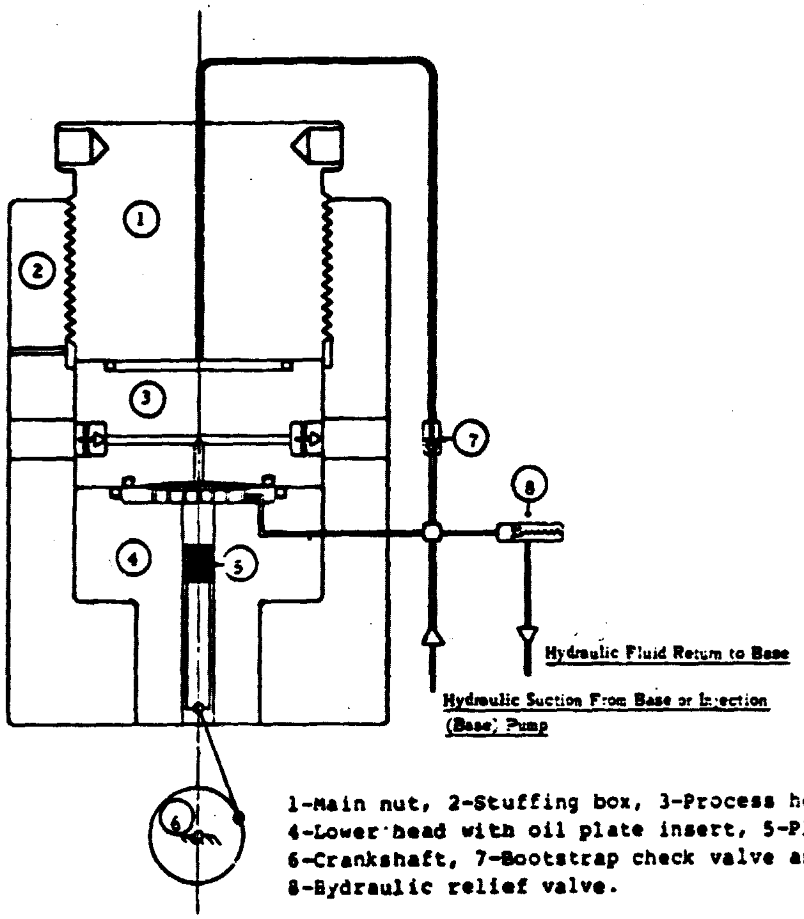

1-Main nut, 2-Stuffing box, 3-Process head, 4-Lower head with oil plate insert, 5-Plunger 6-Crankshaft, 7-Bootstrap check valve and 8-Hydraulic relief valve.

Bootstrap closure (U.S. Patent No. 3,052,188).
(Figure courtesy of Pressure Products Industries, Hatboro, Pa.)

Figure 3. Bootstrap Closure

NASA/JSC uses a Pressure Products compressor with the bootstrap closure and reported that the principle works.

Pressure surges can be expected when pumping at high pressures, especially when balancing the high pressure in the test cell cavity under cryogenic conditions. Every consideration should be given to dampening these surges during the design stage through coiled tubing or the flattened bourdon tube principal. Under no circumstances should this high pressure system be operated without dampening these impact surges. Table IV lists data showing manufacturers' capabilities.

LOW PRESSURE FLOW SYSTEMS

The low pressure flow systems should consist of four basic systems delineated by their function.

- The GN_2 source for the plummet lifting actuation cylinder 0.55-0.69 MPa (80-100 psi).
- The GN_2 pressure for balancing pressure regulators 1.7 MPa (2,000 psi).
- The GN_2 pressure for pneumatic valve operation.
- The LN_2 for cool-down of the specimen test cell.

These particular systems are basic as far as hardware is concerned. The current hardware at MSFC is functional and adequate, but should be replaced due to its age as it is reconfigured to connect with the proposed new system and to incorporate up-dated control instrumentation. During the replacement, consideration should be given to the increase oxygen and nitrogen volume requirements when operating at 2.07 MPa (2,000 psi) compared to a test operation at 172 MPa (25,000 psi). A tube trailer would be more acceptable than the limited volume of 2.07 MPa (2,000 psi) GN_2 and GOX in a 1A cylinder bank.

The oxygen supply is from a bank of 1-A gas cylinders or a tube trailer feeding the suction side of the compressor. This oxygen supply should be evaluated for total hydrocarbons by an inline gas chromatograph. The moisture should be evaluated and kept to a minimum. The oxygen flow should be rough filtered to 25 microns with a final filter prior to the compressor entrance down to 1 micron. A by-pass should be provided for a cleanup of

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TABLE IV

COMPRESSOR DATA

COMPRESSOR DATA:	
Process Gas	Oxygen
Mol. Weight	32
Cp/Cv Value	1.4
Suction Pressure	200-2000 PSIG
Suction Temperature	Ambient
Discharge Pressure	25,000 PSIG
Flow Required	Fill 1/2 $in.^3$ chamber in 5-10 minutes
COMPRESSOR DATA:	
Type	Metal diaphragm
Number of Stages	Two
Discharge Temperature - Approx.	150^o F
MATERIALS OF CONSTRUCTION:	
Process Side	Monel 400
Process Check Valves	Monel 400
Process Seals	Viton
Oil Seals	Buna N
Diaphragm (Process & Oil Side)	Monel 400
Middle Diaphragm (Leak Detection)	Brass
Process Piping	Monel 400

ACCESSORIES:

- Interstage gauge, cooler and rupture assembly
- Oxygen cleaning
- Special halocarbon pulsing oil for the high pressure plungers

the oxygen gas when required. A hydrocarbon cleanup can be attained by flow through silica gel and a molecular sieve.

TEST CELL

Due to the central importance of the test cell function, several areas should be considered. Some of these points are covered within other specific areas of discussion, but are again addressed with respect to the test cell assembly.

- Material Selection--This effort was required to assess any changes felt necessary for operation of the existing system at 82.7 MPa (12,000 psi) oxygen pressure. Changes are recommended. The philosophy behind this effort is to recommend whatever changes are necessary to achieve the ultimate goal of 172 MPa (25,000 psi) as long as the lesser goals stated is inclusively covered. For these philosophical reasons, as well as Monel versus Inconel preferences stated earlier, age and accumulated stress, we recommend redesign and fabrication of the test cell from 400 Monel. Additional points stated below must be considered in redesigning the test cell.
- A faster test cell closure and release is necessary to improve testing efficiency (Figure 4). An interrupted thread or "gun-bolt" design with adjustable screw stops should receive attention during the design stage. Improvement in the time for closure and release of the cell itself, would obviously increase the production rate of compatibility testing. More materials could be tested within a standard work day.
- Consideration should be given to redesigning the internal pressure balancing system so that current component improvements may be incorporated.
- The seal design and materials with regard to the striker pin is an area that must receive attention during redesign.
- Alternative methods for heat source and temperature control should be addressed. **(Details discussed in Section V)**
- A better means of event sensing (14, 21) should be incorporated and is specifically addressed elsewhere. In addition, the faster the response and more sensitivity that can be achieved in pressure and temperature measurement can only substantiate the validity of event occurrence and provide additional data for the reaction. (Details discussed in Section V)
- The possibility for design consideration being given to the size and shape of the test cell itself (16) should be addressed. The potential need for this lies in the unknown but potential changesin oxygen reactivity at pressures greater than 138 MPa (20,000 psi), as well as the kinetic, thermodynamic, and mechanistic nature of the ignition reactions.

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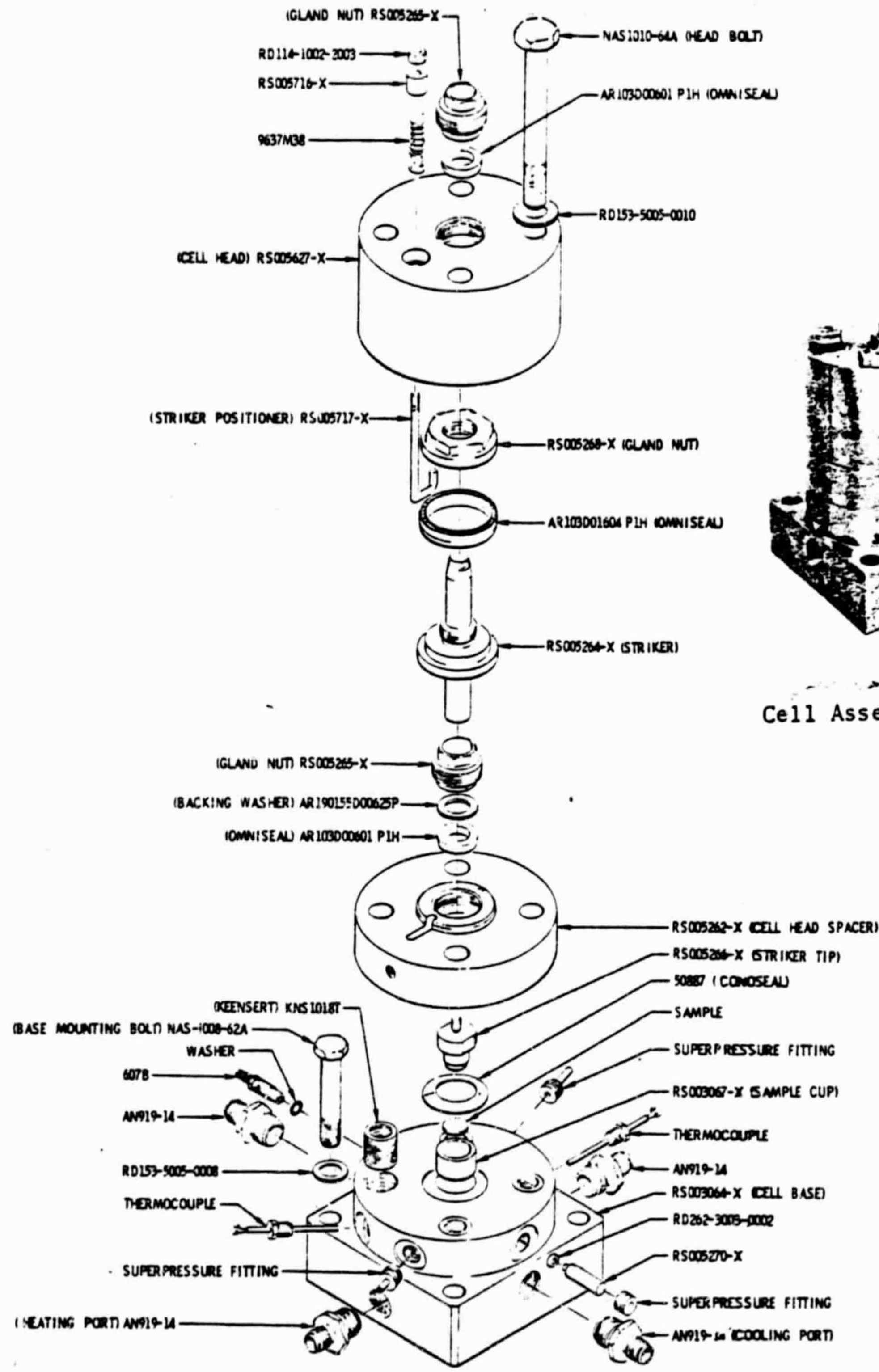

Impact
Cell Assembly

Figure 4. Impact Test Cell

The structural evaluation of the current test cell was based on using K-Monel material with a safety factor of 4. Since Inconel 718 was used in lieu of K-Monel, a gain in safety factor was acquired. The maximum designed pressure in the oxygen cavity was 103 MPa (15,000 psi). Proof pressure of the impact test cell was accomplished at 103 MPa (15,000 psi).

The re-design of the impact test cell should be premised on a few salient features. There should be an awareness that rapid heating due to gas surging into confined spaces can produce a hazardous situation. It is important the test cell re-design feature the following.

- Minimum volume--maximum surface ratio.
- Consideration for the mass of the receiver.
- Heat transfer coefficient of the material.
- Number of paths available for heat dissipation.

V. INSTRUMENTATION

The current instrumentation should be replaced due to the rapid advancements in electronics since the components were installed. The redesign should incorporate some of the following approaches.

TEMPERATURE SENSING AND CONTROL

The planned temperatures ranging from that of Liquid Oxygen (LOX) to 400° Celsius need to be measured continuously and the measured temperatures should be as near as practical to the temperature inside the test cell. The temperature sensing system should be readily compatible with the requirements for temperature control of the cell. The use of strategically placed thermocouples meets the requirements for cell temperature sensing. Four thermocouples symmetrically oriented and as near to the inner test cell wall as practical should yield satisfactory temperature sensing (see Figures 5, 6). Operational tests will be necessary to determine the amount of deviation of approach from the true temperature inside the test cell. These tests can also yield the best processing of the four sensed temperatures to yield the true test cell temperature. The averaging in pairs (1 and 3) and (2 and 4) should yield good results (see Figure 5).

(Figure 7) shows the display approach for the temperature and control system. Three of the four thermocouple probe units are connected to temperature display units, while one of the four is connected to a temperature display and control unit. Omega type "T" thermocouple probe units can be used to cover the range of -200° C to +400° C with 1.5° accuracy from -200° C to 0° C, and a 1° Accuracy from 0° C to 400° C. It is recommended that all four thermocouples be monitored to best estimate the test temperature while using one thermocouple output for control to simplify the control function.

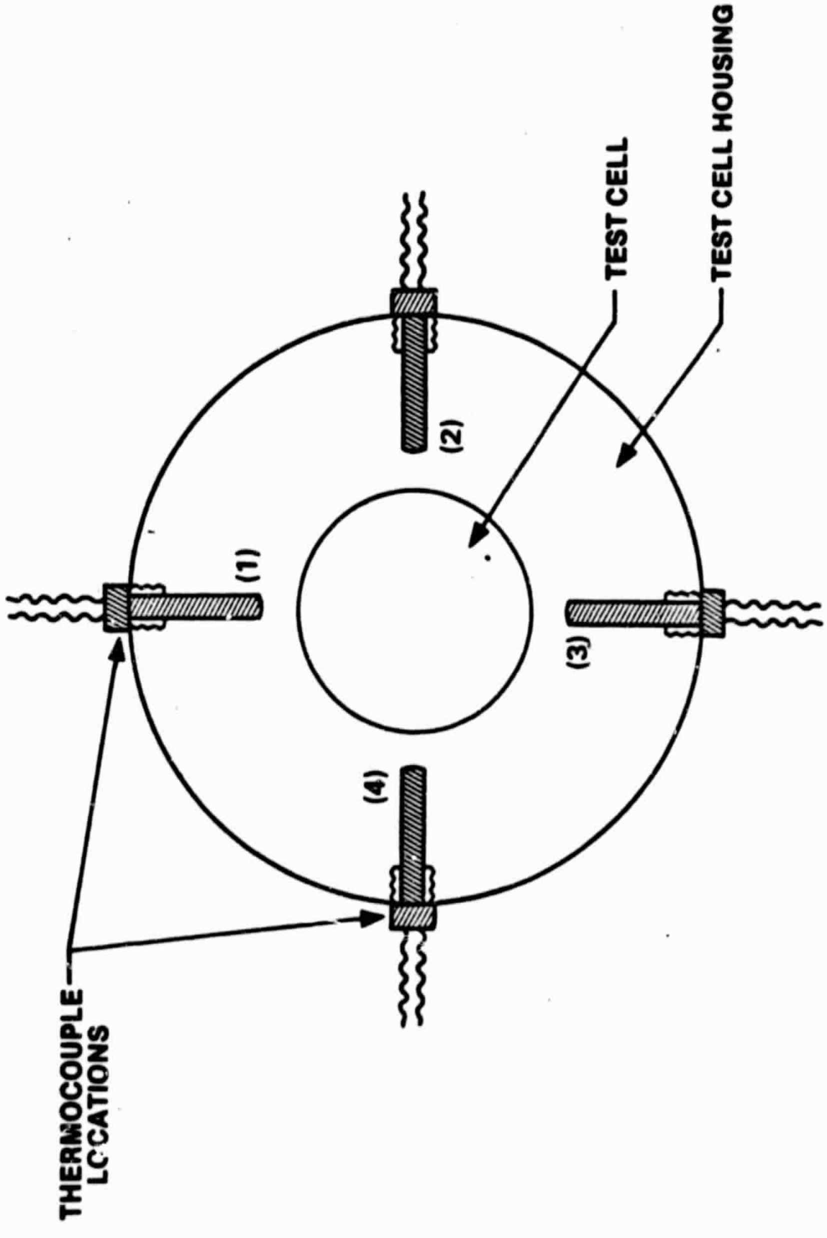

Figure 5. Thermocouple Locations

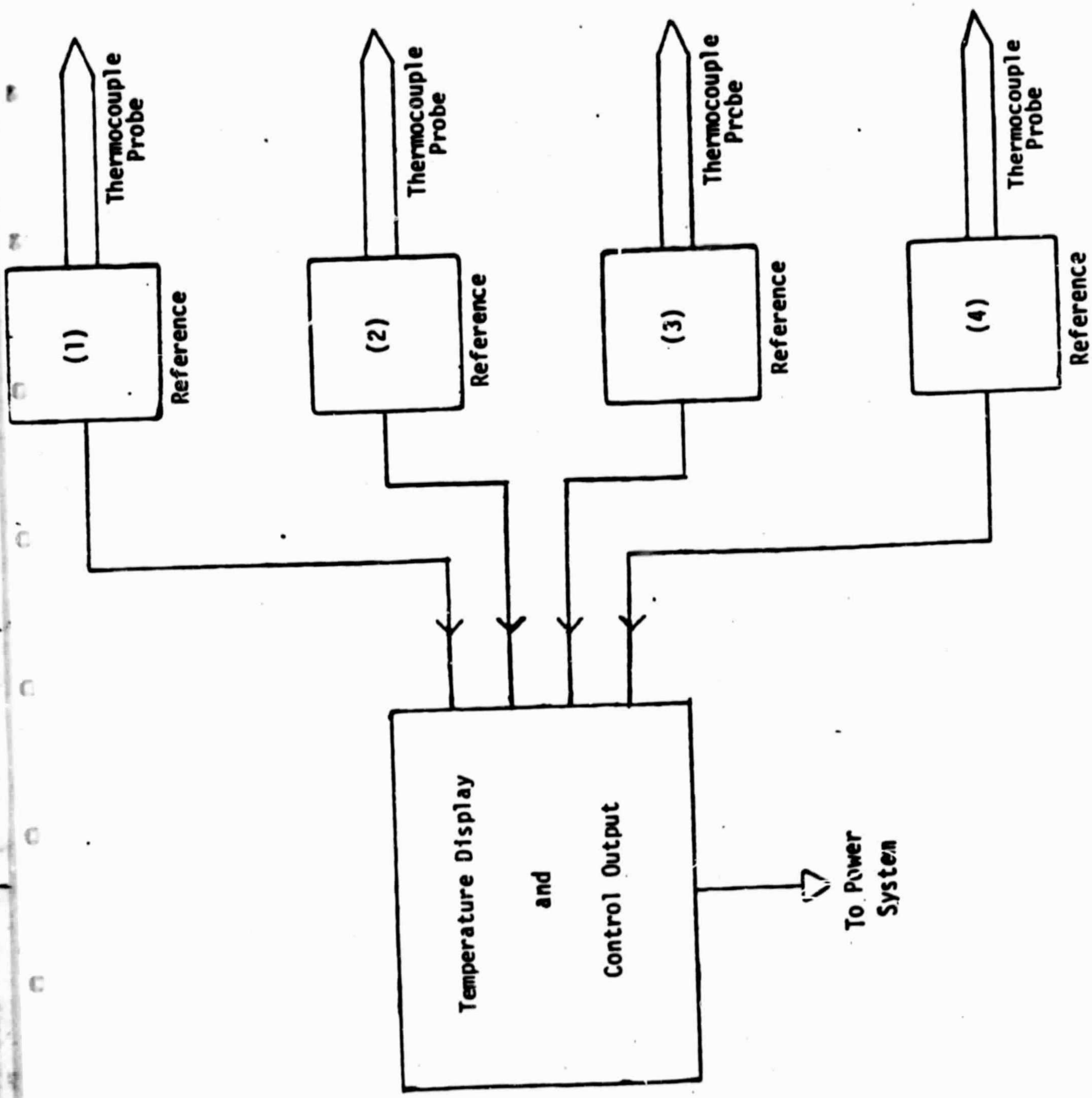

Figure 6. Temperature Sensing System

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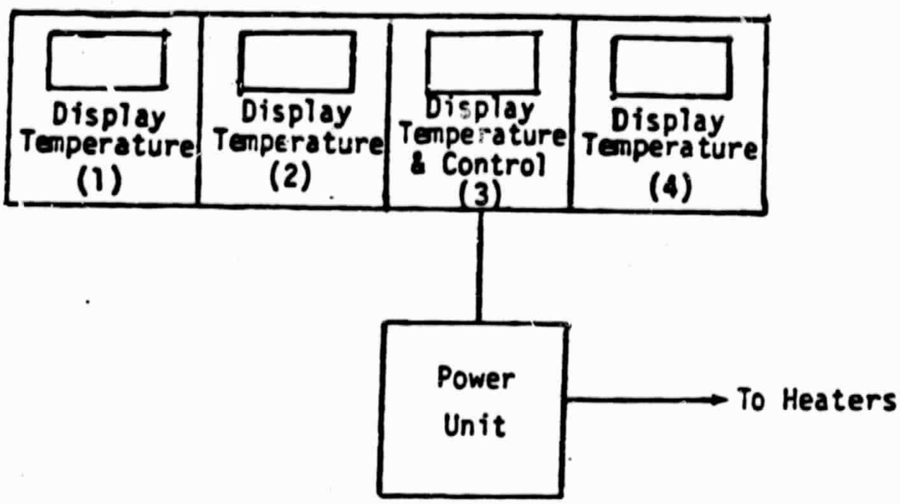

Figure 7. Temperature Display and Control

Also this approach gives redundancy since the system is still operational with only one probe functioning. The output of the temperature display and control unit is fed to the power unit. The power unit provides adequate power to heat the test cell to the upper temperature of +400° C. In this section it is assured that about 1500 watts will provide adequate heating. The power unit is shown (Figure 8A) which provides adequate current handling capacity to power the heater units. (Figure 8B) shows an optional power unit which would provide lower voltage in D.C. to produce heating as an alternate approach.

When temperature control of the specimen test cell is required above ambient temperature, the temperature control system which only provides heat can adequately control the temperature. For reducing temperature it will be necessary to provide a steady cooling to the test cell in order to vary its temperature. This throttle cooling can be provided by a steady flow of liquid nitrogen into the test fixture. With this combination heating and cooling the temperature controller can provide the heating as required to achieve the desired test temperature.

All the components required to fabricate the temperature sensing and control system are readily available with the exception of custom packaging and heater elements for custom voltage operation. These items, although custom built, are not high cost or long lead time items. The packaging and integration can be performed by local Huntsville, Alabama instrumentation companies. All thermocouples digital displays, probes, reference junctions, and basic controllers are readily available from vendors such as Omega Engineering whose information was used for budgetary data.

EVENT SENSING

Event sensing for 82.7 MPa (12,000 psi) and greater pressures presents problems because of the pressure.

In order to define a system for event sensing it is necessary to determine some physical interaction associated with the event

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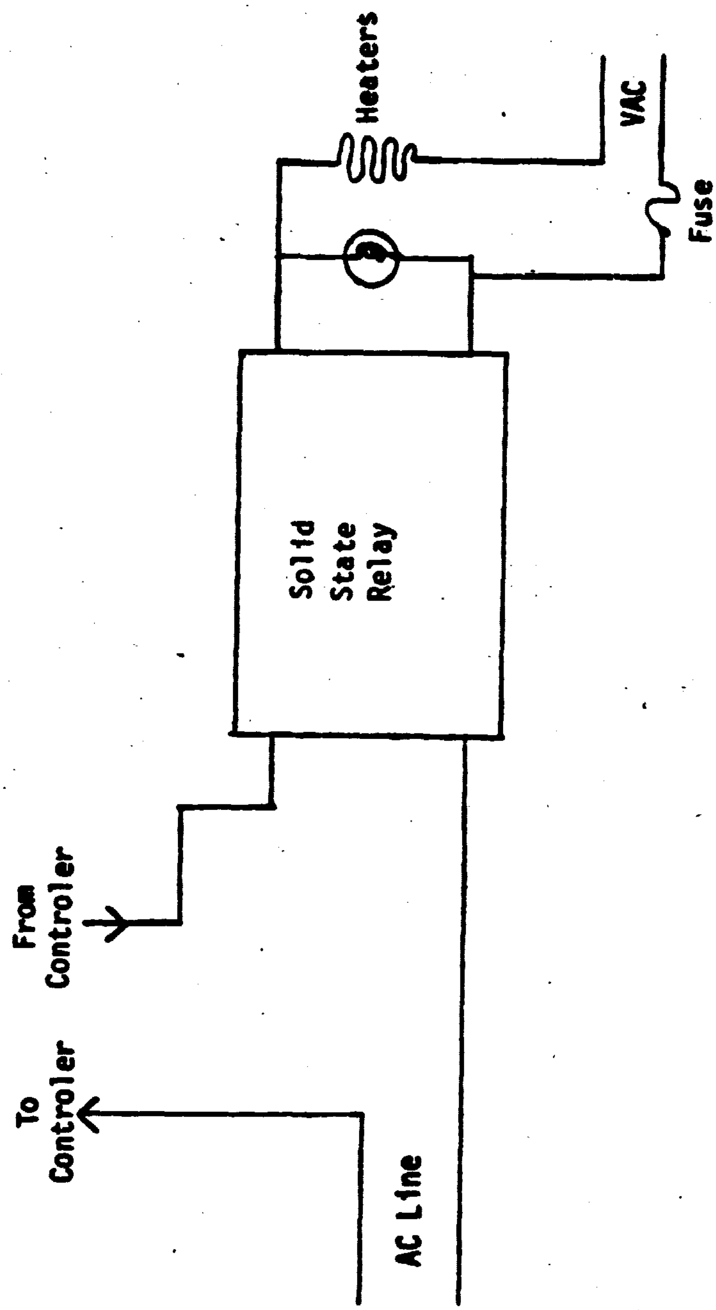
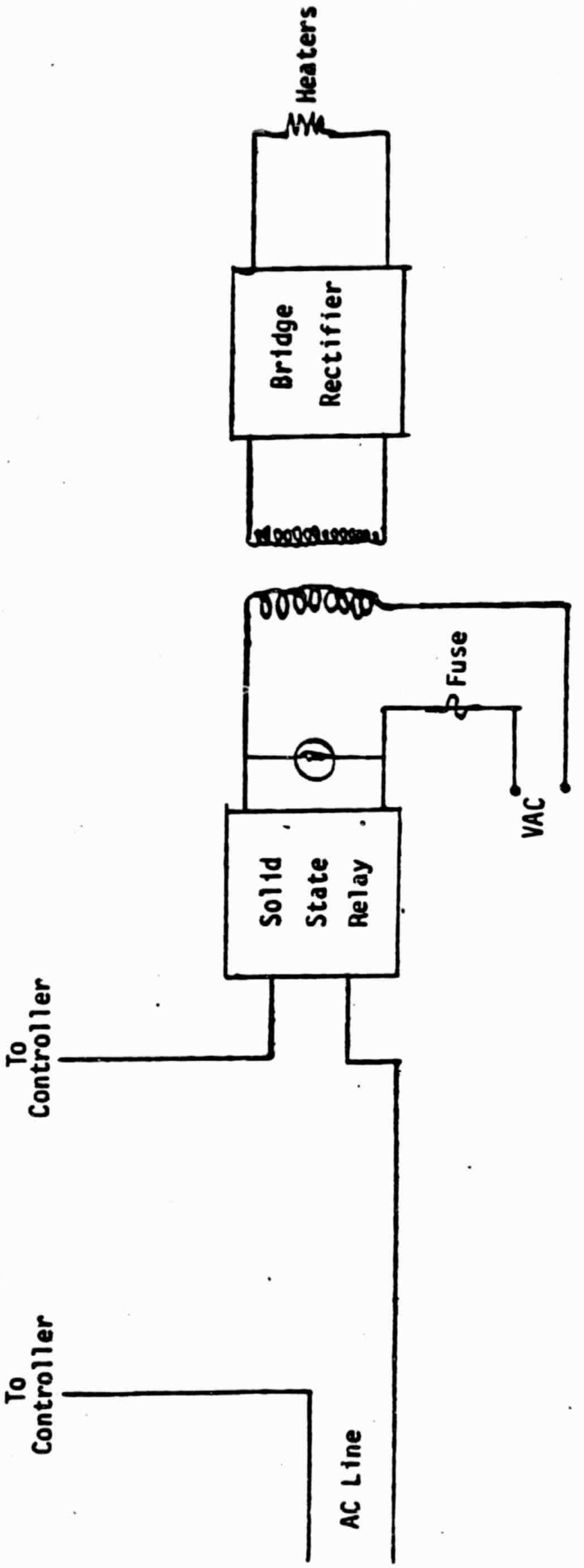


Figure 8.A. Power Unit



OPTIONAL HEATER POWER UNIT

Figure 8B

Figure 8.B. Optional Heater Power Unit

which is measurable or which leads to such a measurable interaction. The events of interest such as rapid oxidation should liberate measurable energy. It is here assumed that such events will emit energy in the visible and/or near infrared spectrum. Although viewing ports for eye observation into the test cell might be used for event sensing, this approach has some very definite disadvantages, not the least of these being safety and high pressure sealing.

In order to overcome these problems a methodology was devised which would allow the detection of the emission of radiation in the test cell using extremely small ports and remote measurement of the occurrence. Fluitron, Inc. (22) indicates they have been successful in fabricating leak proof sapphire windows, by parallel surface grinding, to pressures of 207 MPa (30,000 psi); however, they have never been to 400° C with this assembly. Figures 9-A and 9-B show the general approach to transmitting the emitted radiation from the specimen test cell. A very small window in the upper portion of the test cell is used to transmit radiation to a coupled fiber optic. The use of two ports on opposite sides of the test cell will provide reasonable coverage for reliable event sensing. These ports can be made very small which will allow sealing at very high pressures and eliminate port breakage at such pressures. The coupled optical fiber will transmit radiation to a remote location for detection, processing and displays. Available detection systems for use with such optical fibers allow a wide variety of measurements. The following capabilities can be provided:

- Rapid sensing of the occurrence.
- Sensing of short duration events.
- Variable setting to define event occurrence.
- Measurement at different portions of spectrum by detector selection.

Figure 10 shows the operational block diagram of components required to detect emitted radiation after it is transmitted from the test cell via a fiber optic. The voltage at the output line represents the intensity of the radiation coming from the fiber

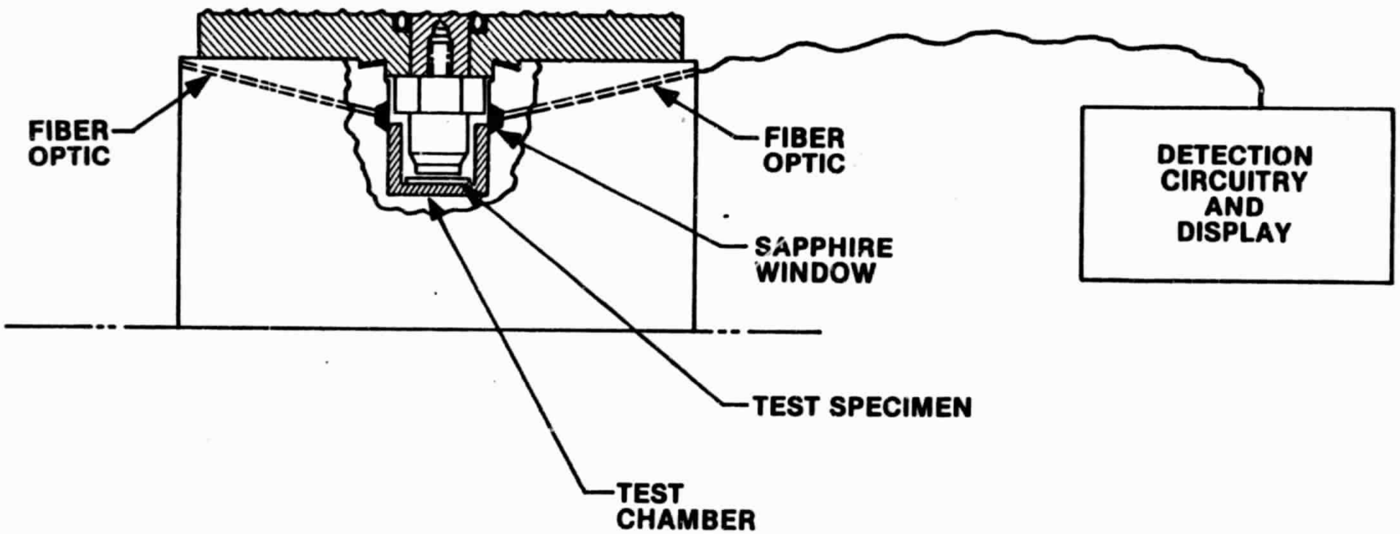


FIGURE 9-A. EVENT SENSING

FIGURE 9-B. EVENT SENSING

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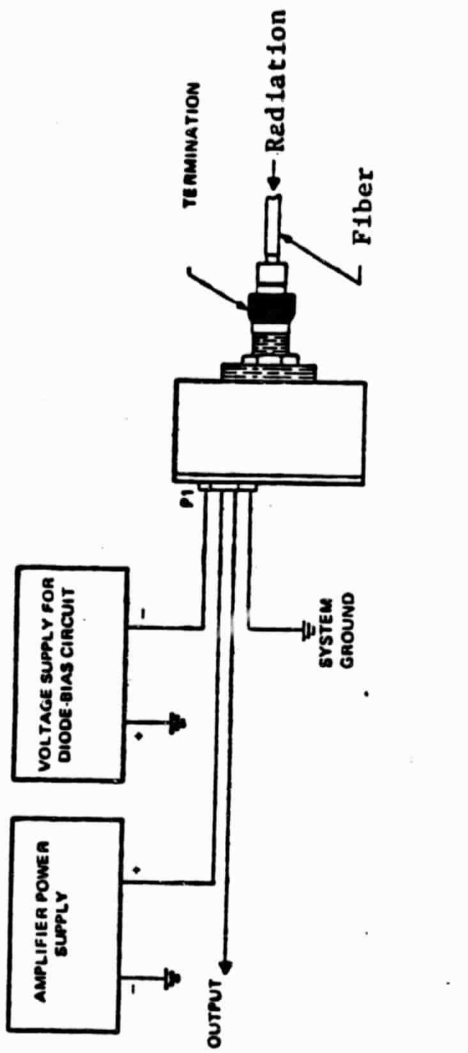

Figure 10. Detection System Operational Block Diagram

optic. Whenever an event occurs in the test cell that emits radiation, the voltage at the output will change.

Figure 11 shows the block diagram of the detection system and the electronic system that does the post detection processing. The threshold level sense circuitry senses whenever the output of the detection circuitry goes above a pre-set level and causes an event indicator to go on and stay on until manually reset. This gives an indication on an event occurrence independent of event duration. Simultaneously the duration sense circuitry senses the output of the detection circuitry for events above threshold that are sustained for a duration above a pre-set time period, and produces an indication of such an event. Also the output of the detection system can be monitored on an oscilloscope for visual display. A storage oscilloscope should provide long term viewing of output to determine the temporal nature of the emitted radiation due to the event.

CALIBRATION

The thermocouple temperature measurement system should be validated by placing a test thermocouple inside the test cell to correlate the four thermocouple readings with the actual temperature inside the test cell.

The purpose of the event sensing drive is to determine whether an event occurred or not. Calibration of such a device consists of setting threshold devices inside the electronics. Observation of signal outputs from tests with known events should be used to determine the proper setting of these threshold levels.

The pressure sensor selected has a built-in electrical signal simulator to calibrate the electronics associated with the pressure sensor system.

Pressure standards are available as complete compact and transportable units with the means of pressure generation and regulation built into one compact housing, the heaviest mass inside being 2 kilograms.

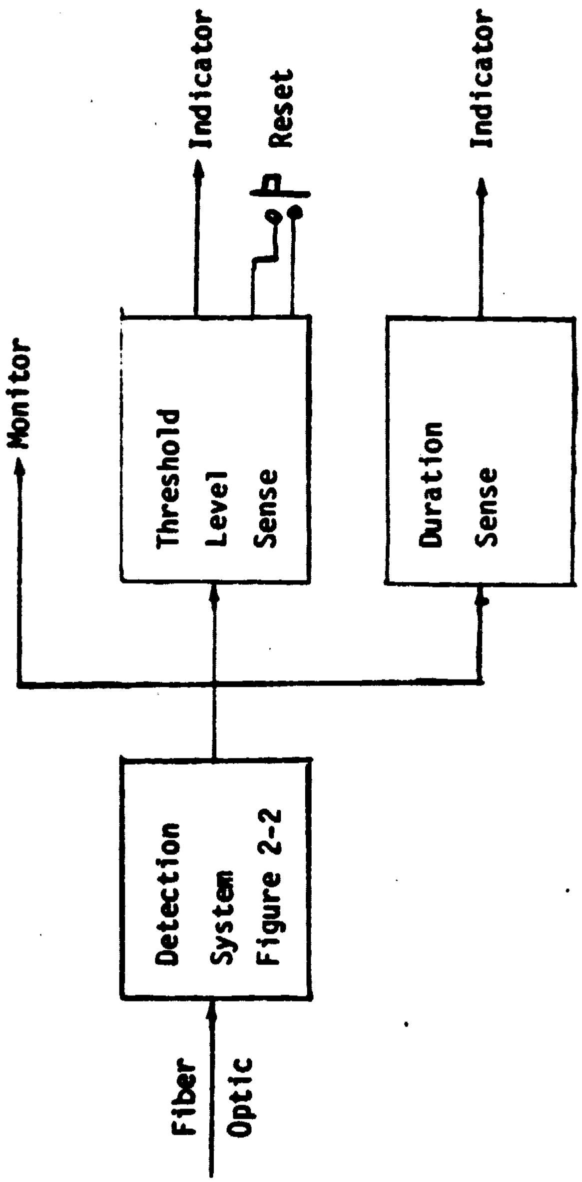

Figure 11. Event Indication System

By the extension of pressure range pressure, measurement from zero to 689 MPa (100,000 psi) is possible.

The accuracies available with this calibration are of the "N" and "S" type. The "N" class pressure standards are accurate to ± 0.05% of reading over the entire range at a temperature of 20° C ± 5° C and at a standard "g" value. "S" accuracy pressure standards are accurate to ± 0.01% of over the full range.

These instruments (DH Instruments, Incorporated) have traceability to the National Bureau of Standards.

A block diagram using this type of pressure transducer as a pressure measurement system is shown in Figures 12 and 13. The power supply shown provides excitation for the transducer and the signal conditioner provides the proper electronic buffering, filtering, and amplification of the transducer's output. The indicator and alarm panel provides electronic read-out of the test cell pressure and gives alarm indication if a preset pressure is exceeded. This preset pressure limit is adjustable. Also electrical outputs can be provided to control a "shut down" if a preset pressure is exceeded. This system can also be designed such that alarm and "shut down" outputs are provided if pressure transducer output is lost during testing.

The Teledyne Taber pressure transducer (Model 2107) has an excellent track record (21); however, it has similar inadequacies to other transducers as far as this oxygen system application is concerned.

The pressure sensing cavity is of stainless steel material and the high temperature limit is below the stated 400^0 C requirement.

To compensate for the temperature limitations, it will be necessary to offset the transducer at the specimen test cell by approximately 2 inches. This will affect the response; however, the response decay can be calculated. The offset installation should be held to a minimum and be only sufficient to limit temperature buildup in the transducers to its designed limit.

It is possible to compensate for pressure drift due to excessive temperature by placing a temperature pickup on the transducer and compensating electronically. Although the transducer cavity is of stainless steel material there is no record at current operating pressures of a dead-end connection of an offset transducer burning in an oxygen environment.

Fluitron, Incorporated will fabricate transducers of Monel-400.

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PRESSURE SENSING

The function of pressure instrumentation is to measure physical phenomena and to present this measurement in an intelligible and usable form.

A survey of available pressure transducers adequate to meet requirements led to the choice of the strain gage type transducers for the pressure sensing element. Such pressure transducers are available with the following characteristics:

Measurand Fluids	All fluids compatible with 316 stainless steel. **Options available.**
Full Scale Output	3.0 ± 0.015 MV open circuit per volt excitation. Calibrated at 10.00 VDC excitation.
Zero Balance	0.00 ± 0.03 MV per volt at +70°F.
End Point Linearity	Within ± 0.15% FSO.
Hysteresis	Less than 0.15% FSO.
Repeatability	Within 0.10% FSO.
Resolution	Infinite.
Natural Frequency	0-10.000 PSI range .... 267KHz 0-15.000 PSI range .... 317KHz 0-20.000 PSI range .... 354KHz 0-25.000 PSI range .... 392KHz 0-30.000 PSI range .... 429KHz 0-40.000 PSI range .... 496KHz 0-50.000 PSI range 550KHz
Proof Pressure	Application of 1.5 times rated FS pressure will not cause changes in transducer performance characteristics.
Burst Pressure Rating	Greater than 4.0 times rated FS pressure not to exceed 150,000 PSI.
Compensated Temperature Range	-30°F to +170°F. **Options available.**
Operating Temperature Range	-100°F to +250°F.
Thermal Sensitivity Shift	Less than ± 0.005% FSO per °F over CTR.
Thermal Zero Shift	Less than ± 0.010% FSO per °F over CTR.
Triaxial Mechanical Shock	30 G's applied for 11 milliseconds will not cause change in transducer performance characteristics.
Acceleration Error	Less than ± 0.0015% FSO per G.
Excitation	10 volts DC or AC RMS recommended. 15 volts maximum.
Input Resistance	350 ± 3.5 ohms at +70°F. Input circuitry symmetrical.
Output Resistance	350 ± 5.0 ohms.
Insulation Resistance	Greater than 10K megohms at 50 VDC between all terminals in parallel and transducer case at +70°F
Pressure Connection	AE F250-C with bleed hole for ¼" high pressure tubing.
Pressure Cavity Volume	0.012 cubic inches.
Electrical Receptacle	Stainless steel MS type MS3102E-14-2P. Standard wiring: Excitation +A, -D, Signal +B, -C. **Options available.**
Enclosure	Entire housing and pressure cavity of stainless steel. All electrical components sealed against adverse environmental conditions.
Weight	Approximately 30 ounces.

Options Available

- o Pressure cavity materials of 304 and 347 stainless steel.
- o Double, single internal, or external shunt. Tracking throughout compensated temperature range.
- o Compensated temperature ranges available for any range within-- 100° F to +250° F.
- o Electrical receptacles MS series 5 or 6 pin and pigmy series.

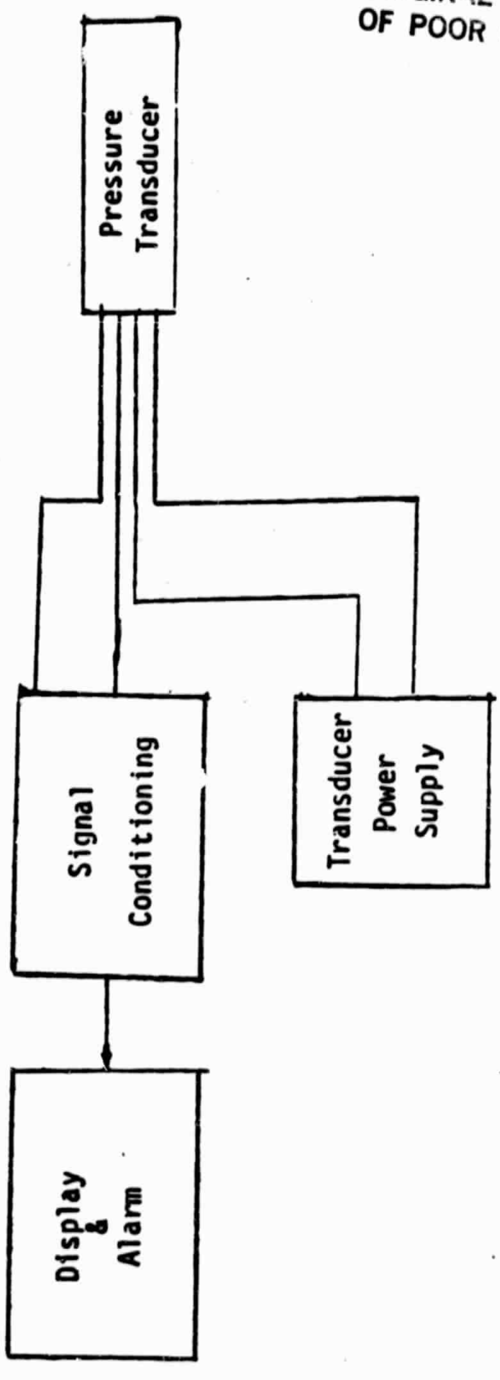

Figure 12. Pressure Sensing Block Diagram

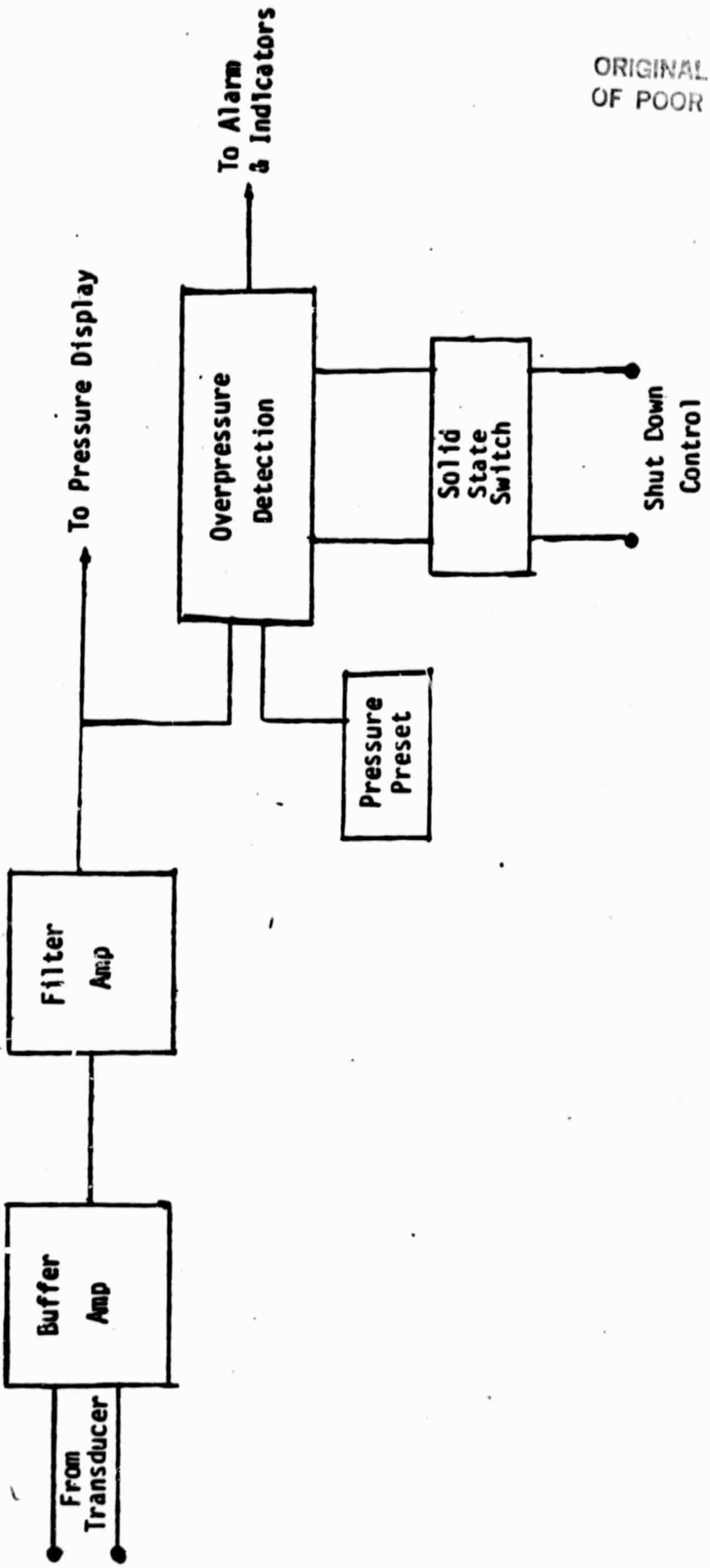

Figure 13. Pressure Sensing Signal Conditioner

VI. COMPONENT SELECTION

The design and fabrication of high pressure oxygen systems should be by competent, experienced people. Therefore the use of as much standard high pressure equipment as possible should be selected from established manufacturers. Although only a limited number of manufacturers are involved, SSI established that sufficient capability exists in the high pressure component area.

High pressure valves, tubing, fittings, and rupture discs are available as standard catalogue items. A long delivery time may be required for the exact sizes and quantities required. High pressure compressors are generally manufactured to customer requirements and are not "off the shelf" items. Three compressor vendors have been identified that have the capability to manufacture a compressor to the requirements of the impact tester system. Each of the compressor manufacturers offers a compressor with different design concepts and options and as would be expected, different prices.

Obviously each and every component cannot be selected prior to the final design. The items listed in the component selection list (Table III) gives the part number (or catalogue number) style, type, size and other pertinent information that would meet the requirements discussed in other sections of this report. A recommended source for the items is also included.

Although only a limited number of manufacturers are involved in high pressure equipment and related instrumentation, the capability is sufficient to meet the needs of the impact tester system. Many of the manufacturers serve a market that is relatively small and does not justify a large "agency" type of marketing service since much of their work is to customer requirements. Therefore, a list of high pressure equipment manufacturers and suppliers is given in Table IV.

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TABLE V

COMPONENT SELECTION LIST

Item #	Quan.	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
1	1	CL6600	Elbow	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	Cost-$71.00/ F375/C Connection
2	1	CT6660	Tee	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	Cost-$76.00/ F375C Connection
3	1	CX6666	Cross	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	Cost-$91.00/ F375C Connection
4	1	60F6633	Straight Coupling	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	/ F375C Connection
5	1	60U6633	Union Coupling	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	/ F375C Connection
6	1	60B6633	Bulkhead Coupling	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	/ F375C Connections
7	1	10V6071	AE Non-Rotating Stem Valve (2-Way)	Monel	3/8"	Autoclave Engineers	79.3 MPa (15,000 psi)	Oxygen	Cost-$400.00/
8	1	60VM6071-OHP	AE Non-Rotating Stem Valve-Air to Open Heavy Duty (2-Way)	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	Cost-$1,100.00/
9	1	10V6071-OHD	AE Non-Rotating Stem Valve-Air to Open Heavy Duty (2-Way)	Monel	3/8"	Autoclave Engineers	(11,500 psi)	Oxygen	Cost-$1,000.00/

COMPONENT SELECTION LIST continued

Item #	Quan.	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
10	1	CB6601	AE Ball Check Valve	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	Cost-$600.00/
11	1	CSX6600	CSX-Special-High Pressure	Monel	3/8"	Autoclave Engineers	-	Oxygen	Cost-$500.00/
12	1	60F6633	Coupling	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	Cost-$250.00/
13	-	-	Tubing 3/8" X 1/8"-$17.00/Ft. Pressure	Monel	3/8"	Autoclave Engineers	30,000	Oxygen	Cost-$17.00/Ft.
-	-	-	30,000 psi @ 100° F @ 400° C (750° F)	-	-	-	-	-	-
-	-	-	(.75) X 30,000 = 22,500 psi	-	-	-	-	-	-
14	-	-	Elbows, Tees & Crosses as Quantity Items	Monel	3/8"	Autoclave Engineers	30,000	Oxygen	Cost-$71.00/
15	1	CK6602	AE High Pressure Surge Check Valve	Monel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Oxygen	
16	1	CXK1202	AE Slim Line Surge Check Valve	Monel	3/8"	Autoclave Engineers	138 MPa (20,000 psi)	Oxygen	
17	1	CXB6600	AE Ball Check Valves	Monel	3/8"	Autoclave Engineers	138 MPa (20,000 psi)	Oxygen	
18	1	CX06600	AE O-Ring Check Valve	Stainless Steel	3/8"	Autoclave Engineers	138 MPa (20,000 psi)	Nitrogen	Teflon O-Ring Material-SS Std.

COMPONENT SELECTION LIST continued

Item #	Quan.	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
19	1	CK06600	AE O-Ring Check Valve	Stainless Steel	3/8"	Autoclave Engineers	414 MPa (60,000 psi)	Nitrogen	Teflon O-Ring Materials-SS Std.
20	1	SWF 6-5	AE Cup Type Line Filter (5 Micron)	Stainless Steel	3/8"	Autoclave Engineers	51.7 MPa (7,500 psi)	Nitrogen	
21	1	SWF 6-35	AE Cup Type Line Filter (35 Micron)	Stainless Steel	3/8"	Autoclave Engineers	51.7 MPa (7,500 psi)	Nitrogen	

Monel Items-Special Order

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COMPONENT SELECTION LIST continued

Item #	Quan.	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
22	1	SLF6600	AE Dual Disc Line Filter (35/65 Micron)	316SS	3/8"	Autoclave Engineers	51.7 MPa (7,500 psi)	Nitrogen	-
23	1	SLF6600 (5/10)	AE Dual Disc Line Filter (5/10 Micron)	316SS	3/8"	Autoclave Engineers	51.7 MPa (7,500 psi)	Nitrogen	-
24	6	CSX9600-1/4"	AE Universal Safety Head	316SS	3/8"	Autoclave Engineers	(60,000 psi)	Oxygen	-
-	6	101A-0438	Body	-	-	-	-	-	-
-	6	2010-0438	Plug	-	-	-	-	-	-
-	6	1010-7434	Hold Down Nut	-	-	-	-	-	-
25	6	1/4 Angle	AE Prebulged Rupture Disc	Monel	1/4"	Autoclave Engineers	276 MPa (40,000 psi)	Oxygen	-
26	6	1/4 Angle	AE Prebulged Rupture Disc	Monel	1/4"	-	52.7 MPa (7,500 psi)	Nitrogen	-
27	1	Model 2107	Pressure Transducer (Built-In Pressure Sim.)	316SS	3/8"	Teledyne Taber	(0-10,000 psi)	Nitrogen	Cost-$1,200.00
28	1	Model 2107	Pressure Transducer (Built-In Press. Simulation)	316SS	3/8"	Teledyne Taber	(0-50,000 psi)	Oxygen	Cost-$1,200.00
29	1	-	Pressure Transducer	Monel	3/8"	Fluitron, Inc.	(0-50,000 psi)	Oxygen	Special Order
30	1	1/2"-385A-U2	General Purpose Thermocouple Well-3/8" Diameter Element	Monel	3/8"	Omega Engineering, Inc.	-	-	Special Order

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COMPONENT SELECTION LIST continued

Item #	Quan.	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
31	1	NB2-2	Thermocouple Head	Aluminum	1/2" NPT	Omega Engineering, Inc.	-	-	Cost-$28.00
32	1	NB2-CPSS-14G-12	Thermocouple Assembly	304SS	1/4" NPT	Omega Engineering, Inc.	-	-	Cost-$47.00
33	1	NB2-CPSS-14G-12	Thermocouple Assembly	Monel	1/4" NPT	Omega Engineering, Inc.	-	-	Special Order
34	1	-	Pressure Transducer Signal Conditioner	-	-	Technology Development, Inc.	-	-	Cost-$5,000.00
35	1	-	Power Supplies and Indicator/Alarm Panel	-	-	Technology Development, Inc.	-	-	Cost-$5,000.00
36	1	-	Event Sensing Detection System	-	-	Technology Development, Inc.	-	-	Cost-$10,000.00
37	1	-	Event Sensing Level & Duration	-	-	Technology Development, Inc.	-	-	Cost-$5,000.00
38	1	-	Indicator Panel	-	-	Technology Development, Inc.	-	-	Cost-$1,000.00
39	3	-	Digital Thermometers	-	-	Technology Development, Inc.	-	-	Cost-$420.00 Ea.
40	1	-	Digital Indicating Temperature Display & Control	-	-	Technology Development, Inc.	-	-	Cost-$650.00 Ea.

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COMPONENT SELECTION LIST continued

Item #	Quan.	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
40	4	-	Temperature Probes	-	-	Technology Development, Inc.	-	-	Cost-$50.00 Ea.
41	4	-	Reference Junction	-	-	Technology Development, Inc.	-	-	Cost-$100.00 Ea.
42	-	-	System Mounting & Wiring	-	-	Technolgoy Development, Inc.	-	-	Cost-$2,500.00
43	-	-	Power Unit-A.C. Heating	-	-	Technology Development, Inc.	-	-	Cost-$2,000.00
44	-	-	Power Unit-D-C Heating	-	-	Technology Development, Inc.	-	-	Cost-$2,000.00
45	-	-	1.5 KW Heater System	-	-	Technology Development, Inc.	-	-	Cost-$1,500.00
46	1	HDD-600/2,000	Metal Diaphragm Two Stage Compressor System	Monel	0.004 CFM	Fluitron, Inc.	25,000 psi	-	Cost-$45,740.00/ Suction-200/ 2,000 psig Discharge-25,000 psig
47	1	3,078/3,033	Metal Diaphragm Two Stage Compressor System	Monel	1.80 SCFM	Pressure Products Industries	30,000 psi	-	Cost-$125,000.00 /Suction-350 psig Discharge-30,000 psig Displacement-3.34/.185 $In.^3$/ Stroke

COMPONENT SELECTION LIST continued

Item #	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
48	#767 (4 1/2")	Gauge	S. Stl. Soc.	1/2 MPT (Black Conn.)	Robert Shaw	(0-5,000 psig)		
49	#767 (4 1/2")	Gauge	S. Stl. Soc.	1/2 MPT (Black Conn.)	Robert Shaw	(0-7,500 psig)		
50	W-15-1-HLR-Exp.	Astratact Type II		1/4 HPF (Exp. Proof)	Pressure Products Industries	(0-15,000 psig)		
51	CX-4604-108	Aftercooler (See B/M-L)		3/8 HP	Pressure Products Industries			
52	#8320A199	Solenoid Valve (Class 1 Group D)		1/4 FPT	ASCO			
53	#709 AEB	AC Motor Starter NEMA NEMA Type 7 Class 1 Group D Exp: Proof with Control Transformer 460 V/120V. with Hand Off Auto Switch in Cover and (3) Type N-21 Overload Relays		0	Allen Bradley			
54	#800H-2HA7	Push Button Station Start-Stop NEMA Type 7 Class. 1, Group D.			Allen Bradley			

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COMPONENT SELECTION LIST continued

Item #	P/N	Description	Material	Size	Supplier	Maximum Operating Pressure	Fluid	Remarks
55	CAT # EMP 9030	Push Button Station Enclosure with (1) Push Button On-Off and (2) Pilot Lights (1) Red and (1) Amber			Crouse Hinds			
56	#EJB 121206-6-9B	Junction Box Class 1, Group D Exp: Proof with (2) 1" NPT, Tap Openings on Each Side and (2) 1" NPT Tap Openings on Top and Bottom			Crouse Hinds			
57	#Z-163	Press: Switch Exp: Proof Class 1, Group D.			Custom Components			
58	ATC Type 319	Time Delay Relay AC Range 1 to 60 Sec.			Pressure Products Industries			
59	#TM 21 K 095	Elapsed Time Indicator OTO 99,999 Hrs. 120V. 60 cy. 2.5 Watts			Herbach & Rademan, Inc.			
60	611G#9163	Pressure Switch	SSTL	Set at 50 psig Decreas-ing Pressure	Dual Snap			

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TABLE VI

HIGH PRESSURE MANUFACTURERS AND SUPPLIERS

1. Almac Cryogenics, Inc.
   1108 26 Street
   Oakland, CA 94607
   Phone: (415) 832-1505
   (Temperature Level and Flow Controls, Sensor Units, Indicators, Transfer Lines, etc.)

2. Autoclave Engineers, Inc.
   The Fred Gasche Building
   2930 West 22 Street
   Erie, PA 16512
   Phone: (814) 838-2071
   (Atlanta Representative:
   Kent L. Fredrick
   2030 Tucker Industrial Road
   Tucker, GA 30084
   Phone: (404) 493-1158)
   (Non-Rotating Stem Valves--High Temperature and Cryogenic Valves, Air Operated Valves, Relief Valves, Line Filters, Check Valves, Safety Heads, Rupture Discs, Valves and Fittings, Gages, Indicators, Transducers, Thermocouples, Electrodes, Tubing and Fittings.)

3. BLH Electronics
   42 Fourth Avenue
   Waltham, MA 02254
   Phone: 617/890-6700
   Locally: Currie, Peak & Frazier
   205/536-1506
   Instrumentation
   Pressure Transducers
   Temperature Sensors
   Strain Gagve Accessories)

4. Chromalox
   (Industrial Heating Products)
   4 Allegheny Center
   Pittsburgh, PA 15212
   (Chromalox Cartridge Heaters)

5. Circle Seal Controls
Technetics Division
Brunswick Corporation
Post Office Box 3666/1111 North Brookhurst Street
Anaheim, CA 92803
Phone: (714) 774-6110
(Valves, Fittings, Relief Valves, Solenoid Valves, Check Valves, Manifold and Instrumentation Valves, Pressure Regulators and Back Pressure Regulators, Dynaflow Relief Valves)

6. Control & Power, Inc.
1920 27 Avenue, South
P. O. Box 6117
Birmingham, AL 35259
Phone: 205/870-0274
(Valves, Fittings & Instrumentation)

7. Cryogenic Energy Company
6533 N. Washington Street
Denver, CO 80229
Phone: (303) 287-3371
(Vacuum Jacketed Pipes and Tubes, Liquid Oxygen-Liquid Nitrogen Trailer Style Dewars)

8. CVI, Incorporated
P. O. Box 2138
Columbus, OH 43216
Phone: (614) 876-7381
(Cryogenic Valves, Cryogenic Pumps.)

9. Flexonics Division
300 East Devon Avenue
Bartlett, IL 60103
Phone: (312) 625-1210
(Flexible Metal Hose and Fittings, Expansion Joints, Ducting, Flexible Connectors, Bellows, Expansion Compensators)

10. Fluitron, Inc.
    30 Industrial Drive
    Ivyland, PA 18974
    Phone: (215) 355-9970
    (Manufacturing-Total Capability Valves, Diaphragm Compressors, Fittings, Reaction Vessels, Containment Vessels)

11. Harwood Engineering Company, Inc.
    South Street
    Walpole, MA 02081
    Phone: (617) 668-3600
    (Tubing and Fittings, Valves-Manual, Check, Automatic and Remotely Controlled, Pumps and Compressors, Pressure Gages, Load Cells, High Pressure Systems for High Velocity Jet Cutting, etc.)

12. High Pressure Equipment Company
    1224 Linden Avenue
    Erie, PA 16505
    Phone: (814) 838-2128
    (Gauges, Pumps, Pressure Vessels, Tubing and Fittings, Couplings, Valves, Intensifiers)

13. Metal Bellows Corporation
    1075 Providence Highway
    Sharon, MA 02067
    (Vacuum Pumps and Compressors, Pressure and Temperature Sensors, Flexibile Couplings, Expansion Joints, Metal Hose Assemblies, Ducting, Fabricated Assemblies)

14. MG Electronics & Equipment Company, Inc.
    808 Wilson Street, N.E.
    Decatur, AL 35601
    Phone: (205) 355-6121
    (ASCO Solenoid Valves, Pressure Switches Relays, Transformers, Wiring Accessories)

15. Parke Hannifin Corporation
Instrumentation Connectors
Division
P. O. Box 4288
Huntsville, AL 35802
Phone: (205) 881-2040
(Process Control and Instrumentation Valves and Fittings)

16. Pressure Products Industries Division
The Duriron Company, Inc.
900 Louis Drive
Warminster, PA 18974
Phone: (215) 675-1600
(Diaphragm Compressors, Valves and Fittings, Reactors and Pressure Vessels, Pumps, Gages, Instrumentation)

17. Omega Engineering, Inc.
One Omega Drive
Box 4047
Stamford, CT 06907
Phone: (203) 322-1666
(Temperature Measurement and Control Components)

18. Orange Research, Inc.
140 Cascade Boulevard
Milford, CT 06460
Phone: (203) 877-5657
(Differential Pressure Gages, Compound Range Gages, Switche, Indicating Switches.)

19. Oriel Corporation
15 Market Street
Stamford, CT 06902
Phone: (203) 357-1600
(Precision Optical Components)

20. Rosemont, Inc.
One Riverchase Office Plaza
Suite 118
Birmingham, AL 35244
Phone: 205/988-5759
(Instruments, Pressure Transducers, Temperature Sensors)

21. Ruska Instrument Corporation
P. O. Box 36010
Houston, TX 77236
Phone: (713) 774-2533
(Digital Direct Reading Pressure Gages, Controllers, Test Sets, Air Data Calibrators, Computer Interfaces, Positive Displacement Pumps, Precision Pressure Standards)

22. Setra Systems, Inc.
45 Nagog Park
Acton, MA 01720
Phone: (617) 263-1400
(Digital Pressure Measurement Systems and Readout Devices)

23. Superpressure, Inc.
8030 Georgia Avenue
Silver Spring, MD 20910
Phone: (301) 589-1727
(Diaphragm Compressors, Pneumatic Test Stands, Valves and Fittings, Pumps and Intensifiers, Shaking Assemblies, Reaction Vessels, Optical Absorption Cells, Union Connectors, Non-Rotating Stem Valves, Check Valves, Pneumatically Operated Valves, Proportioning Valves, High Temperature Valves, Line Filters, Relief Valves, Tubing and Fittings, Swivel Joints, Adapters, Electrical Connectors, Thermocouple Assemblies, Rupture Disc Assemblies)

24. Technology Development, Inc.
500 Wynn Drive (Suite 114)
Huntsville, AL 35805
Phone: (205) 837-7762

(Design and Fabrication of Instrumentation Systems)

25. Teledyne Taber
455 Bryant Street
N. Tonawanda, NY
Phone: (716) 694-4000
(Pressure Transducers-Low Level, High Level, Differential, Pressure Transmitters, Oceanographic)

26. Wahl Instruments, Inc.
5750 Hannum Avenue
Culver City, CA 90230
Phone: (800) 421-2853
(213) 641-6931
(Thermocouples, Calibration Standard, Probes, etc.)

VII. Mechanical Impact Testing of Materials In An Oxygen Environment To 172 MPA (25,000 PSI)

The hardware and the high pressure technology is available for venturing into 103, 138, and 172 MPa pressure ranges (15,000 20,000, 25,000 psi).

This investigation revealed that there is a requirement for additional information about oxygen and materials at these pressures and temperatures.

The impact testing pressure and heating systems lend themselves to additional applications for investigations of oxygen and these additional possibilities should be addressed during the redesign.

SEALS

Seal compatibility for these pressures and temperatures are recommended for maximum operation to 280° C. This is an area where judicious care must be applied in selecting the seal design that will permit leak free testing to 400° C.

The Bal-Seal has some good features for static applications.

The seal problem at the specimen test cell is an area that needs addressing during redesign.

Bal-Seal Engineering Company (Mr. Peter Bartheld) proposed a seal for the striker pin for 172 MPa (25,000 psi) and cryogenic temperatures. Bal-Seal proposes their teflon-glass material with a back-up ring made from Kel-F and a loading spring made from 302 stainless steel. (This loading ring should be from Monel 400 Series). They propose their flange type seal which has the unique advantage that, as the temperature decreases, a greater load is applied to the striker pin shaft.

During any high pressure application, the force that is required to move the striker pin is determined by the area of seal contact with the striker pin shaft. Bal-Seal recommends a seal with a design that combines flexibility with minimum area of contact, which is their part number 2FEHUR304-113G.

SSI does not concur with their recommendation for this seal at the striker pin due to the excessive "break" force for the striker pin during operation with a seal of this type.

Essentially, SSI recommends the use of the bellows for a seal at the striker pin because the "break" force will always be predictable.

CLEANLINESS

Cleanliness cannot be over emphasized when operating at these pressures and temperatures.

The equipment layout should be such as to permit easy scrubbing and maintenance of the testing area.

FITTINGS, VALVES AND TUBING

The fittings and valves for 82.7 MPa (12,000 psi) or 172 MPa (25,000 psi) are made from the same size piece of material. The only difference is the flow system inside diameter and the valve seats. As the pressure increases the flow path size decreases, with a corresponding slight increase in cost due to the design and machining problems encountered.

All of the components are special order and the delivery time can be up to six (6) months. If a volume production is scheduled at the time an order is placed a cost benefit can be anticipated. Even tubing is a special order at these pressures.

MATERIAL, SPECIMEN TEST CELL AND COMPRESSOR

Certified billets of Monel-400 are available and are needed for the compressor heads and the specimen test cells. These billets are not plentiful but they can be found. However, they are expensive.

The machining operations on the specimen test cell are complex and of course costly.

The two most expensive sections of the system are the specimen test cells and the compressor section.

The two stage compressor can be made the most flexible because it may be controlled so that one or two compressors are the source of high pressure oxygen depending on the pressure required for testing. This is the most flexible pressurization technique; but again, it is the most expensive. It presents twice the maintenance problems.

The two stage, individual stage controlled, compressor is the type recommended due to its flexibility in operation.

Since a relief value is very undesirable at these pressures, automatic unloading by automatically lowering the suction pressure to the compressor should be considered when the system is designed.

Premised on WSTF and JSC experiences the Fluitron, Incorporated, compressor is recommended.

This compressor has Monel-400 material for all oxygen wetted surfaces with a hydraulic drive diaphragm rated at 172 MPa (25,000 psi).

VIII. Cost Analysis

Individual components, recommended materials, measurement and control instrumentation, and design considerations for the high pressure oxygen impact tester have been discussed in previous sections. In some cases more than one manufacturer or vendor had acceptable items or could readily manufacture items to the clients required specifications. Some concepts or recommended items are not essential to the safe or minimal operation of the impact tester but should be seriously considered to obtain the best data while advancing the science and understanding of high pressure oxygen impact testing.

Costs of individual item are discussed in Section VI. as well as estimated costs of research and development items/systems to be developed. The following cost analysis is divided into the various operational sections of the impact tester.

Low Pressure Nitrogen and Oxygen Systems		$15,000
Compressor and Associated Control Systems		60,000
High Pressure Oxygen System Excluding Dead Weight Tester		37,000
Test Cell - Minimum of Three Required, One Each for Metals Testing, Oil and Grease Testing, and Plastics Testing	3 @ $18,000 each	54,000
Instrumentation		45,000
Tower Refurbishment		6,000
Installation		75,000
Design		36,000
	Total	$328,000

IX. Conclusions and Recommendations

This documents attempts to assimilate the pertinent information needed to understand liquid and gaseous oxygen characteristics in combination with the engineering materials necessary to develop the flow systems for a materials compatibility impact tester for operation in an oxygen environment at pressures up to 172 MPa (25,000 psi) and temperatures from -181° to 400° C.

Current high pressure technology is capable of operation at the required levels, however, no documented information was found indicating previous operations with oxygen at these extremes of temperature and pressures. Therefore, operation in an oxygen environment above 103 MPa (15,000 psi) and to 400° C should be considered in the area of research and development. As a result all of the current MSFC material impact tester systems, with the exception of the tower, should be redesigned to reflect current technological developments, and increased operating pressure to 172 MPa (25,000 psi). Items to be considered are:

IMPACT TOWER AND ASSOCIATED ACCESSORIES

The current tower and associated accessories are meeting requirements, however, it should be reworked to conform with projected requirements.

- The load-cell should be sent to the manufacturer for refurbishing.
- The impact tower accessories should be replaced to bring them in line with current technology.
- Welding of the tower at strategic stress points would produce a more rigid structure.
- Knife edge guides for the plummet in place of rollers would simplify adjustment and aid free fall alignment on the striker pin.

IMPACT TEST CELL

The impact test cell redesign should be similar to the current ones in operation but incorporate features for the improvement of testing.

- The test cell should be redesigned of Monel 400 for temperatures from (-)180° to (+)400° C with design stresses sufficient to operate at 172 MPa (25,000 psi) plus the maximum pressure anticipated due to chemical reaction.
- The base assembly should be redesigned to incorporate resistance heating of the cartridge type or its equivalent.
- The seal design should be changed at the test cell interface to a compression type of the Bridgman design with the proper materials.
- The test cell sample holder volume, sensing probe locations, and event sensing should be addressed in the redesign.
- The striker pin assembly should be redesigned using a bellows or diaphragm for a seal to eliminate the "stick-break" force-pressure problems at the striker. Using this approach the striker "break" force would be a known quantity.
- The redesign should incorporate an impact cell quick opening feature to speed-up testing.
- The redesign should incorporate a more effective event sensing capability.
- The redesign should incorporate a chromatograph-mass spectrometer analysis feature for analysis of the test residual gases.
- The delivery of high pressure oxygen to the test cell should be at ambient conditions and then the temperature should be increased to the test limits desired. This approach will extend the life of the hardware during the initial exploratory testing at extremes of temperature and pressure.
- The location of the temperature, pressure and event sensing sensors in the test cell is a real designing challenge but it can be accomplished so the cell may be readily opened for speciment replacement.

LOW PRESSURE PNEUMATIC SYSTEMS

The pneumatic support systems, i.e., actuation cylinder pressure, pneumatic valve actuation, test cell balance pressure, and the liquid nitrogen cooling systems should be replaced due to age and wear as well permitting reconfiguration to incorporate component improvements.

- The liquid nitrogen test cell cooling system should incorporate a means for throttling LN_2 flow so that the LN_2 may be used as a rapid temperature changing source for the impact test cell.
- The nitrogen test cell balance pressure should be brought up-to-date with current servo capability.
- The nitrogen test cell balance pressure volume should be increased.

HIGH PRESSURE OXYGEN FEED SYSTEM

This system needs to be redesigned to meet currently programmed requirements.

- All oxygen wetted surfaces within this system should be constructed of Monel 400.
- All valves, fittings and tubing intended for this system should be special ordered of Monel 400.
- Relief valves or orifices should not be used in this system. Rupture disc holders should be barricaded.
- Where tubing of this system is exposed to temperature the, operating pressure should be reduced to 75% of that normally recommended.

OXYGEN SOURCE

The current gaseous oxygen source, i.e., eleven 1A cylinders manifolded together should be replaced.

- An MSFC oxygen tube trailer charged to 15.2 MPa (2,200 psi) would give in excess ten times the volume currently available. If volume testing is planned an additional larger source of oxygen will be necessary.
- One of the existing 34.5 MPa (5,000 psi) tube trailers available at MSFC could be used to supply a greater volume.
- This oxygen source should be designed and installed so this system could be connected to the test cell as a source for low pressure testing.
- This system should also be designed and controlled so it may be used for a supply of oxygen to the suction side of the compressor.
- This oxygen supply should be evaluated for total hydrocarbons by an inline chromatograph.

- The moisture should be evaluated and kept to a minimum below (-)55^o C.
- This oxygen source should be rough filtered to 25 microns with a final filter prior to compressor entrance down to one micron.
- A by-pass should be provided for a cleanup of the oxygen when required. A hydrocarbon cleanup can be attained by a flow through silica gel and a molecular sieve.

HIGH PRESSURE OXYGEN COMPRESSOR

The current impact tester system compressor, an Aminco-Corblin (which is now Superpressure, Inc.) motor driven, two stage diaphragm type, catalog number 46-13426 should be replaced. It needs the upper head plates, the check valves and the diaphragms replaced with Monel 400 material to comply with current technology for operation at the projected extremes of temperature and pressure.

Two manufacturers contacted for modification of this compressor indicated they could build another to specific requirements more economically than modifying the current one.

This compressor should incorporate the following.

- Leak free design capable of delivering 207 MPa (30,000 psi) oxygen pressure.
- Contamination free compression.
- Flow rate of 1.75 CFM or greater.
- Corrosion resistant materials (All oxygen wetted parts from Monel 400).
- Leak detection.
- Aftercooler
  The compressor head plate should incorporate water cooling. This will extend the Monel 400 diaphragm life and permit delivery of oxygen to the test cell at ambient conditions, an essential requirement for operation at planned extremes of temperature and pressure.
- Motor starter.
- Automatic "ON/OFF" Control system.
- Automatic unloading system. Since a relief valve is very undesirable at these pressures, automatic unloading by automatically lowering the suction pressure to the compressor should be considered when the system is designed.

- Suction and discharge pressure instrumentation.
- Flow control systems.
- Temperature and pressure switches.
- Oil level switch.

MATERIAL

Studies of materials available for use with temperature and pressure extremes in an oxygen environment indicate that Monel 400 is the most acceptable for this application. Monel 400 is less strong than many of the other metals but sufficient where weight is not a restriction.

Certified billets of Monel 400 are needed for the compressor heads, the specimen test cell and the various valves and components used to control the high pressure oxygen.

INSTRUMENTATION

There have been rapid advances in electronics since the installed units were selected, therefore, these units should be replaced with components incorporating some of the following functions with improved capability.

- Instantaneous indication of existing variables in a system.
- Recording of variables.
- Programming of variables with time.
- Actuation of control circuits and recording of events by time.
- Visual and audio indications of malfunctions.

These functions are applicable to temperature, pressure, and event sensing.

TEMPERATURE SENSING AND CONTROL

- The test cell temperature sensing system should be readily compatible with the requirement for controlling and recording the temperature of the specimen test cell from (-)181° C to (+)400° C. Four symmetrically placed thermocouples will do this. The Omega Engineering "T" thermocouples will perform this function satisfactorily.

- The throttling of liquid nitrogen to the test cell will provide an adjunct to the heating and permit the temperature controller to provide the heating as required to achieve the desired test temperature.

CALIBRATION

The thermocouple temperature measurement system is validated by placing a test thermocouple inside the test cell to correlate the test thermocouple readings with the actual temperature within the test cell.

EVENT SENSING

The extremes of pressure and temperature programmed for the material impact tester present problems of high pressure sealing. The current system is inadequate and is not being used.

In order to overcome these problems and allow the detection of the emission of radiation in the test cell a very small window located in the upper segment of the test cell and coupled to a fiber optic will transmit radiation. The use of two such event sensing parts on opposite sides of the test cell will provide reasonable coverage for event sensing.

The coupled optic fiber will transmit radiation to a remote location for detection processing and display. Available detection systems for use with such optical fibers allow a wide variety of measurements such as--

- Rapid sensing of the occurrence.
- Sensing of short duration events.
- Variable setting to define event occurrence.
- Measurement of different portions of spectrum by detector selection.

CALIBRATION

The purpose of the event sensing drive is to determine whether an event occurred. Calibration consists of setting threshold devices inside the electronics. Observation of signal outputs from tests with known events should be used to determine the correct setting of threshold levels. Two sensing element ports will permit laser calibration for accurate use in the visible or near IR range with NBS traceability.

PRESSURE SENSING

The pressure instrumentation measures physical phenomena and presents thi measurement in an intelligible and usable form for recording and controlling events.

- This system should provide a power supply for transducer excitation and signal conditioning.
- An indicator for electronic recording and readout of test cell pressure.
- An alarm if preset pressure is exceeded.
- This system should also incorporate an alarm and "shut down" if the pressure transducer is lost during testing.

The Teledyne-Taber pressure transducer (Model 2107) has an excellent track record; however, the pressure sensing cavity is of stainless steel and the operating temperature limit is below the 400° C requirement.

To compensate for the temperature limitations, it will be necessary to offset the transducer at the test cell by approximately two inches. This will affect the response, however, the response decay can be calculated.

There is no record of a stainless steel "dead-end" connection of this type encountering problems from an oxygen environment.

CALIBRATION

The pressure sensor selected has a built-in electrical signal simulator to calibrate the electronics associated with the pressure sensor system. Pressure standards are available with accuracies of the "N" and "S" type as complete, compact, and transportable units with the means of pressure generation and regulation built into one compact housing, with the heaviest weight inside being 2 kilograms.

AREAS OF CONCERN

There are areas of uncertainty to be considered when undertaking any task for the first time, especially, at these planned extremes of temperature and pressure in an oxygen environment.

Some areas of concern considered pertinent enough to warrant additional study are:

- Reactive nature of oxygen at pressures greater than 138 MPa (20,000 psi).
- Oxygen reaction kinetics and thermodynamics.
- The internal shape and dimensions of the material impact test cell itself with respect to the propagation or support of oxidation. [20]

This work would determine the ignition limits and their dependence on temperature and the oxidizing media as well as the analysis of the residuals.

To extend a specific, limited study to a variety of problems to be encountered in the use of various materials under widely differing conditions, there is a need to develop theoretical postulations based on thermodynamics, kinetics and physical properties.

Once a sufficient number of experimental data are accumulated the practical applicability of such a theoretical system can then be tested.

The accumulation of ignition-decomposition characteristics of a sufficient number of related substances would permit the tailoring of a materials properties for a specific application.

Evaluation of material reactions has shown certain data are basic when assessing these reactions, i.e., (1) thermodynamic data, (2) kinetic parameters and (3) physical properties.

These specific parameters are:

- Thermodynamic.
  - Reaction energy.
  - Adiabatic temperature increase.
  - Specific quantity of gas generated.
  - Maximum pressure in the test cell.
- Kinetic.
  - Reaction rate.
  - Rate of heat production.
  - Rate of pressure increase in the test cell.
  - Adiabatic time to maximum rate.
  - Apparent activation energy.
  - Initial temperature of detectable exothermic reaction.
- Physical.
  - Heat capacity.
  - Thermal conductivity.

There is a close relationship between the exothermic reaction energy and the adiabatic temperature rise which can be measured by appropriate instrumentation. The specific volume of the gas generated by the reaction, together with the adiabatic temperature rise determines the maximum pressure developed in the test cell.

The basic thermochemical variable that requires consideration is the temperature-dependent, concentration-dependent rate of the exothermic reaction. Both the total energy of reaction and rates of heat generation and heat accumulation must be determined.

Pressure changes in the test cell will also be dependent upon the reaction rate. From the adiabatic temperature rise and the adiabatic self heat production, the derived variables, i.e., such as activation energy, adiabatic time to maximum rate, and maximum time to pressure rise can be calculated.

The heat generation rates of specific samples depend on temperature, degree of conversion, and often, previous thermal history. The start of a particular heat release rate will be detected at widely different temperatures, depending on sensitivity of the instrumentation.

The primary objective of these thermo-kinetic studies is to aid the selection criteria and establish the use parameters for a material in a GOX, LOX environment through the application of limited data.

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APPENDIX I

FOMBLIN Y DATA

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The extreme aggressiveness of oxygen in the pure state, or diluted with small quantities of other gases, involves serious problems each time lubricants come into contact with atmospheres of that type.
The difficulty of finding materials suitable for this use has induced equipment designers to exclude lubrication, or else to separate the zone where oxygen is present from the one in which the lubricant acts, using diaphragms or the like.
The latter solution, which would appear the most logic wherever it is feasible, entails the serious risk of causing oxygen to come into contact with the lubricant in the event of accidental rupture of the separator elements, so the lubricant must be capable of withstanding such contact.
These difficulties have in some cases aroused the attention of legislative authorities; for instance, in the German Federal Republic law forbids the use of lubricants which have not been approved by a special Federal Institute (1).
A valid contribution to these problems is offered by Fomblin* Fluorinated fluids, which are perfectly compatible with oxygen and possess thermal stability, chemical inertness and lubricating properties capable of meeting every type of requirement.

Properties of Fomblin Y Fluorinated fluids

Fomblin Y fluids are linear perfluoropolyethers, available in several grades with differing average molecular weight and viscosities. Table 1 gives some properties of the Fomblin Y grades suggested for oxygen application. For fuller details reference should be made to the specific technical bulletin "Fomblin Y Fluorinated fluids" edited by Ausimont.
Different grades of Fomblin Y are miscible one with the other, yelding types having properties intermediate between those illustrated.

Viscosity-temperature properties

These properties are illustrated in the graph in Figure 1. As compared with the fluorinated compounds oxygen compatible on the market, Fomblin Y fluorinated fluids have viscostatic properties that are among the best.

(1) This institute is the BUNDESANSTALT FUR MATERIALPRUFUNG (BAM) - 1 BERLIN 45, Unter den Eichen 87

* = Ausimont trade mark

Lubricating properties

Fomblin Y fluids are good lubricants in boundary lubrication conditions.
Under such conditions they behave as a good additive-free, typical mineral oil.
Fomblin Y also exhibit good EP properties.

Compatibility with oxygen

At atmospheric pressure, no reaction is observed between pure oxyen or air and Fomblin Y Fluorinated fluids up to temperatures around 400°C and not excessively prolonged contact times. For this reason no reference is made here to flash points, combustion or self-igniting temperatures for Fomblin Y fluids, which are to be considered as non-flammable.
At high pressures the maximum service temperature of Fomblin Y in the presence of oxygen decreases.
Its value is also affected by the manner in which the gases and the fluids reach contact; in particulary by pressure application speed.
This phenomenon is not confined to the Fomblin fluids. but is general.
Test methods capable of reproducing as faithfully as possible actual service conditions, when a lubricant is in contact with oxygen, have therefore been developed.
In addition to those adopted by the BAM of Berlin, methods and test results on the compatibility of oxygen placed in contact with the Fomblin fluids are described hereafter.

Static oxygen resistance

Tests carried out in Montedison's laboratories, heating Fomblin Y Fluorinated fluids at 200°C in a stainless steel autoclave with oxygen at 200 kg/cm² and analyzing the fluid after 160 hours have shown that the sample thus treated remains completely unaltered.

Liquid oxygen impact test

This test allows determination of the compatibility of lubricants with liquid oxygen.
It reproduces the service conditions of a lubricant for valves or compressor used in air separation plants, in rocket motors and the like.
Fomblin Y fluids, tested in accordance with the U.S. standard MSFC-SPEC. 106 B «Testing Compatibility of Materials for Liquid Oxygen Systems», passed the test. They have thus been approved for use in liquid oxygen systems by the National Aeronautics and Space Ad-

ministration - NASA (G.C. Marshall Space Flight Center, Alabama) and by the Naval Ship Engineering Center of the U.S. Navy.
Copies of three letters of approval are shown in Enclosures 1, 2 and 3 (1).
Fomblin Y 06 passed the tests as appeared in the NASA - White Sands Test Facility Report of August 27, 1980. At pressures up to 10,000 psia, has been found to be non-reactive under the conditions of the tests.
The first test, the Heated Mechanical Impact Test, was performed according to the requirements of Part 2 of Test No. 13 of NHB 8060.1A. Using gaseous oxygen, with the impact Energy of 72 foot-pounds a pressure of 10,000 psia, a temperature of 150 °F, no reaction occured after 20 tests.
The second test, the Heated GOX Pneumatic Impact Test, was performed according to the requirements of Test No. 14 of NHB 8060.1A.
At a pressure of 10.000 psia and a temperature of 150 °F, no reaction occured after 20 tests.

Ignition temperature in oxygen

This has been determined by the Bundesanstalt für Materialprüfung, Berlin for each Fomblin Fluid type heating in a cylinder 500-700 mg of product in an oxygen atmosphere at 100 kg/cm² and 20°C, up to reaction temperature (Enclosure 4).
The results are reported in Table 2, which also gives the oxygen pressure corresponding to ignition temperature.

Oxygen impact resistance under pressure

This test reproduces what occurs when there is an instantaneous pressure increase of the oxygen in an environment having a relatively low pressure, and in which the lubricant is present at a certain initial temperature.
During this instantaneous pressure, which in an early approximation may be considered as adiabatic, the temperature of the system increases to a value which is a function of the initial conditions (initial temperature and pressure) and of the final pressure reached. If the final conditions exceed the stability limits of the products, these ignite.
The results of these determinations, conducted by the BAM of Berlin, are shown in Figures 2 and 3.

In these figures, the lower zone of the temperature-pressure graph defines for each possible initial fluid temperature the maximum oxygen pressure with which the fluids could come into contact, without danger of ignition.

Injection in oxygen

This test reproduces what occurs when in a membrane compressor for oxygen, operating with the fluid under examination, the membrane breaks with a consequent injection of the fluid into the gas. A 50/50 mixture of Fomblin Y 04 heated at 50°C, was injected into a stainless steel autoclave containing oxygen at 150°C and 260 atm. The sample, analized after about 30 minutes of dwell in the oxygen, was absolutely unaltered, demonstrating the resistance of the fluid to oxygen under the conditions described.

Maximum service temperature

For all Fomblin Y Fluorinated fluids, this temperature must not exceed 250°C (2). In fact, if for some of them a higher temperature is feasible, for technical reasons it was not possible to determine at the impact test the corresponding pressure.

Fomblin Fluorinated greases, T series

By appropriately thickening Fomblin fluids, greases for advanced lubrication can be prepared. Some of these greases are presented by Ausimont as Fomblin Fluorinated greases, T series. Some of the properties of these greases are given in Table 3, but here again reference should be made to the specific literature for fuller details.
The Fomblin Fluorinated greases, T series, have also been examined and approved by the BAM, Berlin for use in contact with oxygen.
The results are given in Table 4 and Figures 5, 6 and 7.

(1) These letters indicate Fomblin Y Fluorinatec fluids as Brayco 810, 811, 812 and 813 oils, respectively. This is the name with which they are sold in the U.S.A.

(2) The maximum service temperature for each grade must be 100 °C lower than the ignition temperature as per Table 2.

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Table 1 — General properties of Fomblin Y Fluorinated fluids

Property	Type Y 04	LOX	Y 25
Kinematic viscosity at 20°C, cs	35	120	250
Pour point, °C	—70	—41	—35
Volatility (%weight loss for 24 hours at 149°C)	60	—	7
Volatility (%weight loss for 100 hours at 80°C)	—	5.0	—

Table 2 — Ignition temperature of Fomblin Y Fluorinated fluids in an oxygen atmosphere

Fomblin Fluorinated fluids	Ignition temperature	Corresponding oxygen pressure
Y 04	360 ± 5	215
LOX	385 ± 5	220
Y 25	395 ± 5	230

Table 3 — Some of the properties of Fomblin Fluorinated greases, T series

	OT 20	UT 18	RT 15
Penetration ASTM D217, mm/10 at 25°C			
— without mechanical work	285	280	275
— after 10,000 cycles	345	310	290
Pour point, °C	> 200	> 200	> 200
Service temperature range, °C	—70/+100	—30/+150	—20/+200

Table 4 — Compatibility of Fomblin Fluorinated greases, T series, with oxygen

	OT 20	UT 18	RT 15
Ignition temperature, °C	225 ± 5	310 ± 5	320 ± 5
Corresponding pressure, kg/cm²	180	200	200

Figure 1 — Kinematic Viscosity of Fomblin Y Fluorinated fluids vs temperature (Chart ASTM D 341 - E)

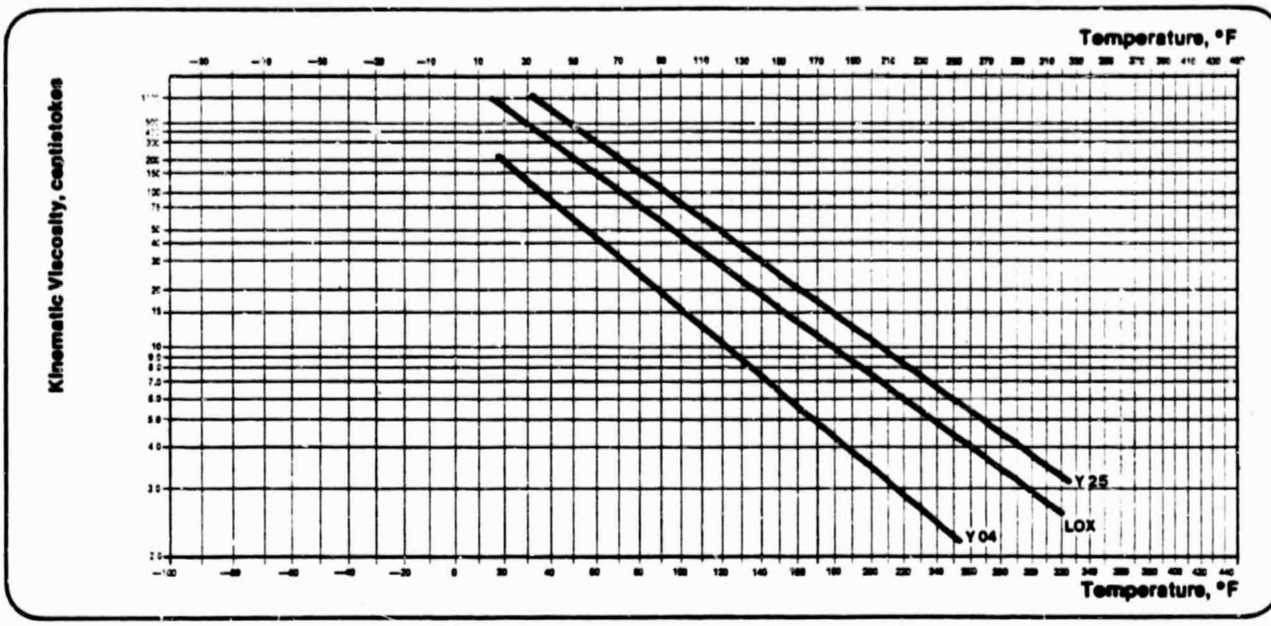


Figure 2 — Pressure vs temperature plot for Fomblin Y Fluorinated fluid Y 04

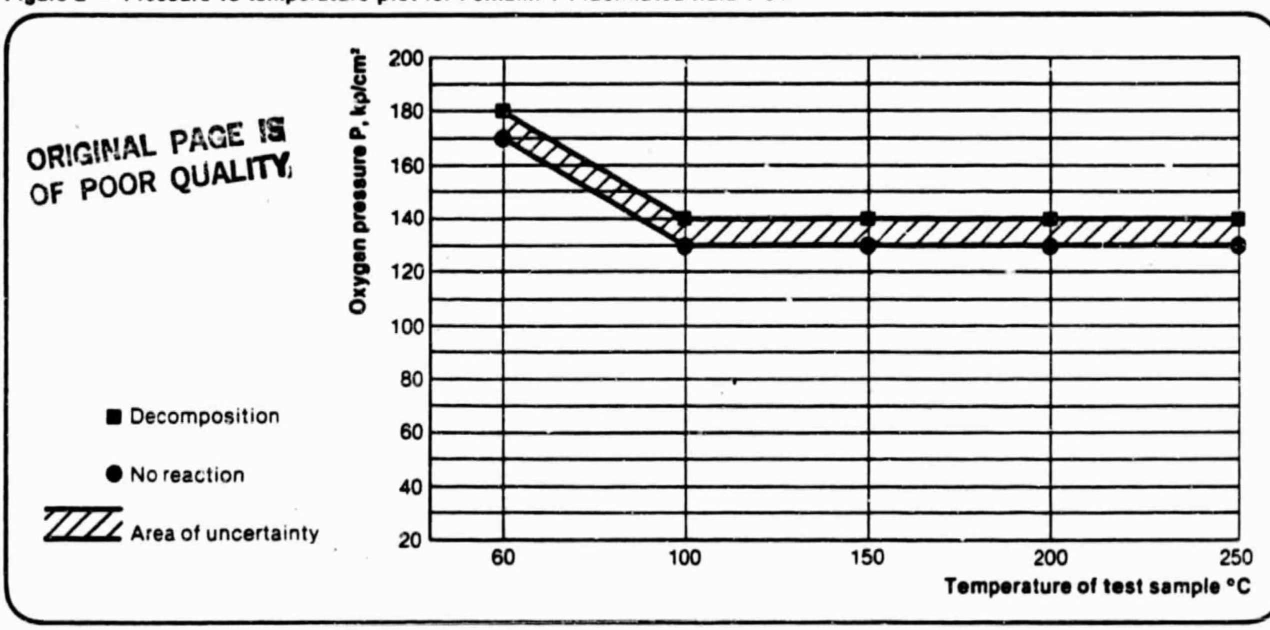
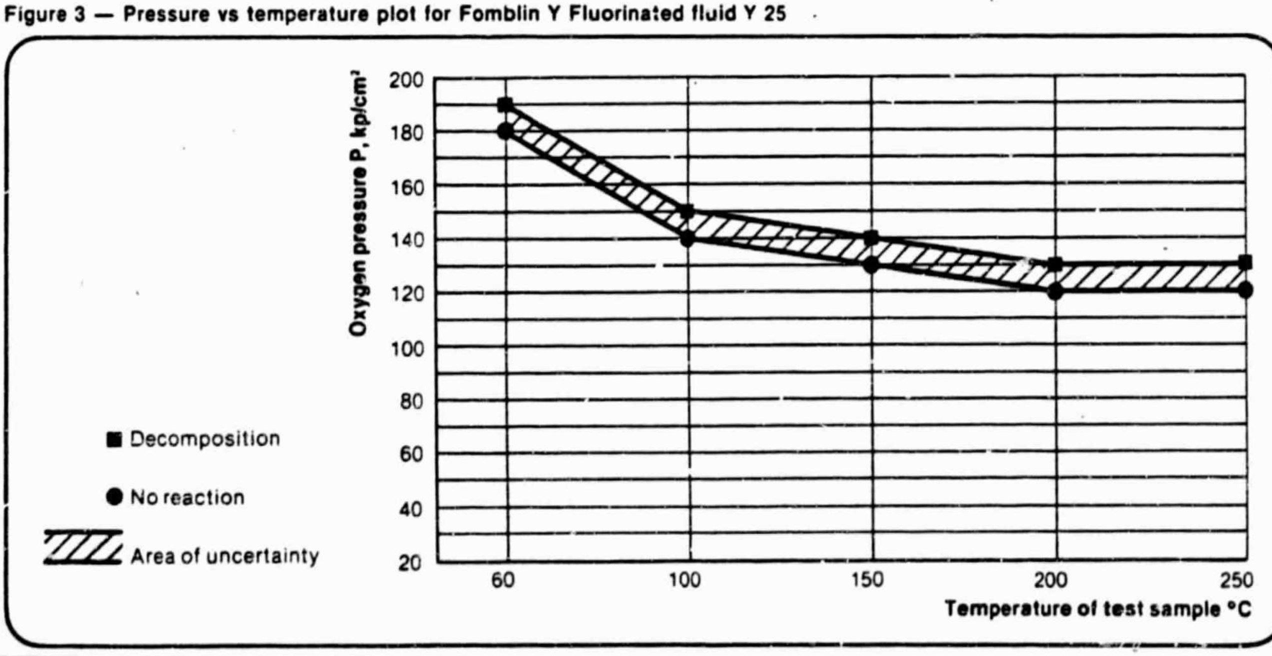


Figure 3 — Pressure vs temperature plot for Fomblin Y Fluorinated fluid Y 25



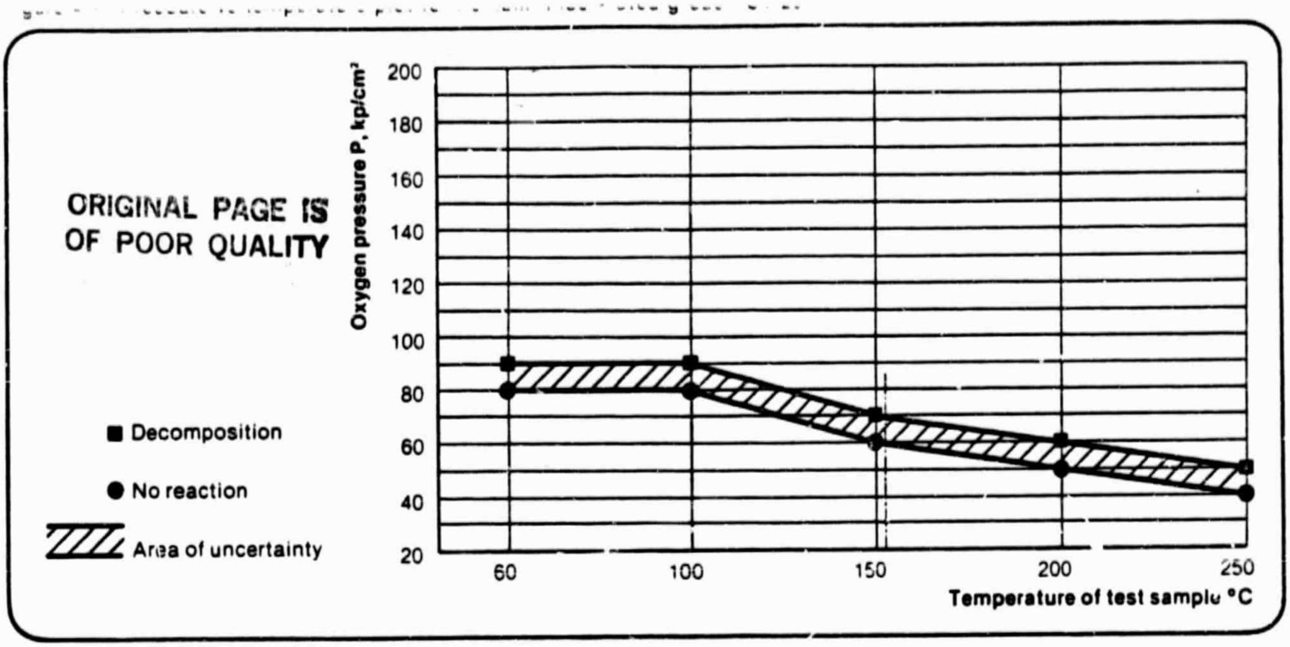


Figure 5 — Pressure vs temperature plot for Fomblin Fluorinated grease UT 18

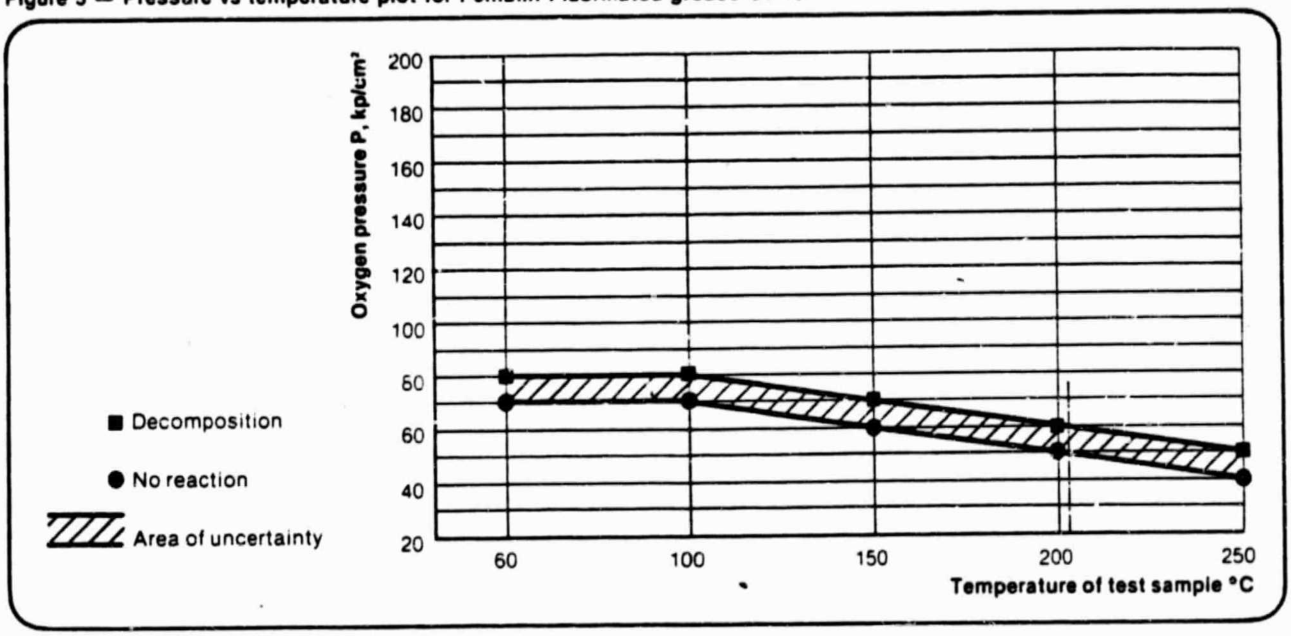
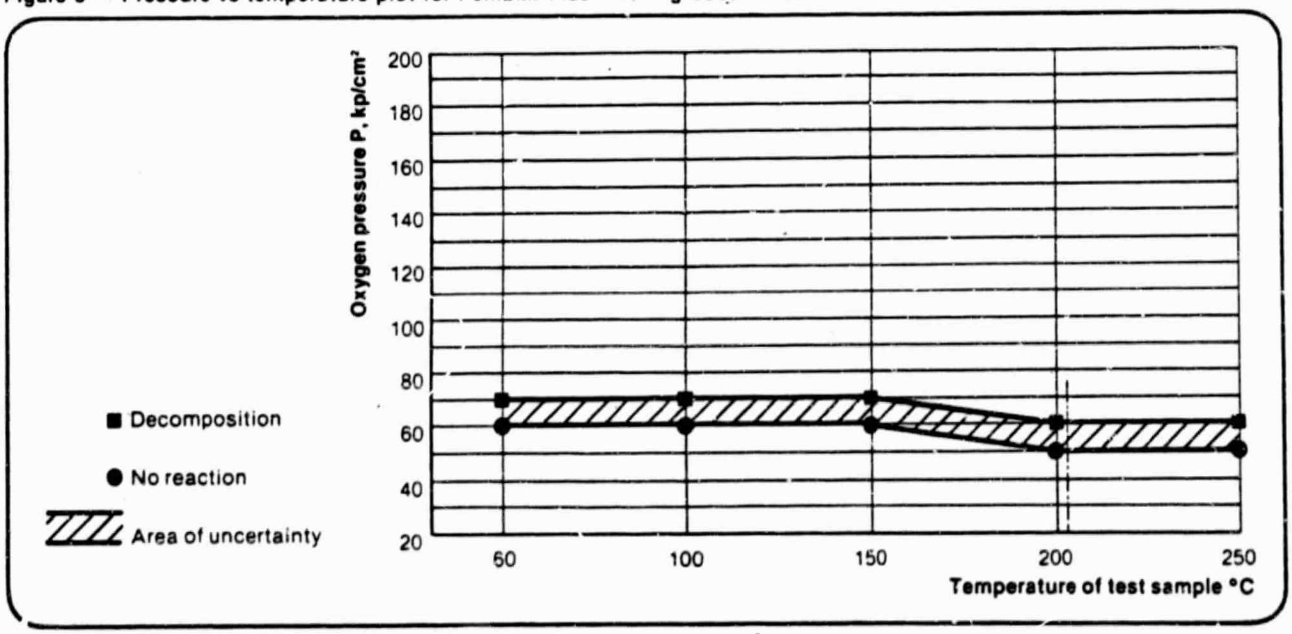


Figure 6 — Pressure vs temperature plot for Fomblin Fluorinated grease RT 15



Enclosure 1

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

IN REPLY REFER TO

S&E-ASTN-MC-69-98

JUN 1 8 1969

Dr. M. Z. Fainman
Director of Research
Bray Oil Company
1925 North Marianna Avenue
Los Angeles, California 90032

ORIGINAL PAGE IS OF POOR QUALITY

Dear Dr. Fainman:

The samples of Brayco 631A grease and Brayco 810, 811, 812, and 813 oils you submitted have been evaluated for compatibility with liquid oxygen by the procedures outlined in MSFC-SPEC-106B, "Testing Compatibility of Materials for Liquid Oxygen Systems."

Brayco 631A grease and Brayco 810, 811, 812, and 813 oils met the required criteria and are approved for use in liquid oxygen systems.

Sincerely yours,

R. J. Schwinghamer

R. J. Schwinghamer
Chief, Materials Division
Astronautics Laboratory

Enclosure 2

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

REPLY TO ATTN OF: EH01 (MC 74-12)

DEC 1 8 1974

Mr. Richard A. Steenrod, Jr.
Post Office Drawer L
Bridgeton, Missouri 63044

Dear Mr. Steenrod:

The samples of Fomblin Y-25 S-1, Y-25 S-2, Y-25 S-3, and Y-25 S-4 have been evaluated for compatibility with liquid and gaseous oxygen at 10,000 psia by the procedures outlined in NHB 8060.1A. The above samples met the acceptance criteria of NHB 8060.1A for Type D materials contingent on each manufacturer's batch being evaluated to ensure LOX/GOX compatibility.

Sincerely,

R. J. Schwinghamer

R. J. Schwinghamer
Director
Materials and Processes Laboratory

NAVAL SHIP ENGINEERING CENTER
CENTER BUILDING
PRINCE GEORGE'S CENTER
HYATTSVILLE, MARYLAND 20782

IN REPLY REFER TO
6101F:AIB:an
10350/2
Ser 670

ORIGINAL PAGE IS
OF POOR QUALITY

2 -JUL 1969

Dr. M. Z. Fainman
Bray Oil Company
1925 North Marianna Avenue
Los Angeles, California 90032

Dear Dr. Fainman:

In response to your letter of 26 June 1969 forwarding results of tests conducted by the George C. Marshall Space Flight Center, Bray Oil Company's "Brayco 814-813" fluids and "Braycote 631A" grease will be placed on the list of acceptable materials in the revised BUSHIPS INSTRUCTION 9230.14B.

Sincerely yours,

H. F. King

Enclosure 4

BUNDESANSTALT FÜR MATERIALPRÜFUNG
(BAM)
4.4

BAM 1 Berlin 45 Unter den Eichen 87

Firma
Montan-Chemsa GmbH

6 Frankfurt/Main
Corneliusstraße 9

Ihr Zeichen	Ihre Nachricht vom	Unsere Zeichen	Fernruf-Durchwahl	Berlin-Dahlem, Unter den Eichen 87
Ch 1-1461/ AH/sch	6.6.69	9251/69; 4-1806	7699 443	9. Febr. 1970

Betr.: Prüfung von "Fomblin"-Gleitmitteln auf Reaktionsfähigkeit mit verdichtetem Sauerstoff

Wir übersenden Ihnen den Bericht über die Prüfung von 16 "Fomblin"-Gleitmitteln auf Ausbrennsicherheit gegen Sauerstoff-Druckstöße.

Wir werden der Berufsgenossenschaft der chemischen Industrie empfehlen, die Stoffe in die Liste der geprüften und für geeignet befundenen Gleitmittel aufzunehmen. Als Herstellerfirma werden wir dabei Montecatini Edison S.p.A., Mailand, angeben.

Durch die Prüfung sind Gebühren nach beiliegendem Gebührenbescheid entstanden.

i.A. Möller

(Dr.-Ing. K.-H. Möller)
Oberregierungsrat

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C-2

The data, information and suggestions are provided for guidance purposes only. No responsibility is accepted for the results obtained therefrom, nor for their utilization in infrigement of possible patent rights.

N-811 E

MONTEDISON GROUP

AUSIMONT
Montedison Intermedi e Ausiliari
Chimici per l'Industria

Via Principe Eugenio, 1/5 · 20155 Milano (Italy)
Telephone: (02) 63331 · Cables: AUSIMONT MI
Telex: 310679 MONTED I PER AUSIMONT

APPENDIX II

FUNDAMENTAL DATA FOR OXYGEN & NITROGEN

Liquid oxygen is pale blue in color, will flow like water, and weights 1.0688 grams per cubic centimeter (23).

One cubic meter of liquid represents 800 standard cubic meters of gas and could build up to a pressure of more than 82.7 MPa (12,000 psi) if confined at ambient conditions.

Oxygen can exist as a gas, liquid or solid. However, it will be liquified when cooled below -181° C at atmospheric pressure. With an increase in pressure, oxygen may exist as a liquid at temperatures above -181° C, but pressure will not keep it in a liquid state above -119° C.

SOME OF THE PROPERTIES OF LIQUID OXYGEN

Boiling point at 1 atm	-183° C or -297° F
Critical temperature	-118.8° C or 181.8° F
Critical pressure	715.6 psig
Density (liquid 1 atm)	71.27/ft^3
Density (gas 1 atm)	0.082716/ft^3
Cu ft of gas/cu ft of liquid (1 atm)	862
Cu ft of gas/gallon of liquid (1 atm)	115.2
Wt of gallon of liquid	9.5316
Specific volume at n.t.p.	12.1 ft^3/16
Heat content of saturated vapor	Btu/16
Heat of vaporization at 1 atm	94 Btu/16
Mol wt	32
Specific gravity at -297° F	1.14

NITROGEN PROPERTIES

Melting point	-209.9° C	-345.3° F
Boiling point	-195.8° C	-320° F
Density	1.25 kg/liter	50.4 lb/ft^3
Specific gravity at 320° F		0.808
Cu ft gas/cu ft liquid 1 atm		696
Cu ft gas/1 gallon liquid atm		93
Lb/gallon of liquid		6.74
Heat of vaporization 1 atm		86 Btu/lb

APPENDIX III

BIBLIOGRAPHY PREFACE

This bibliographical listing of articles and books pertaining to or associated with activities involving gaseous or liquid oxygen enriched environments was compiled to aid those persons involved in this rapidly advancing area of technology.

It is a listing of authors, whether senior, sole or one or multiple authors whose articles are listed.

The numbers at the left refer to the bibliography designation number.

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Contract No.: NASW-1921/70-08-31 64 pages
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Irvine, CA
Avail: NTIS
(Majs: Air, combustion, delrin, ignition, oxygen, teflon)

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Canoga Park, CA 91304
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Bartlett, IL 60103
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25 pages
Avail.: NTIS; SAP: HC $3.25
National Aeronautics and Space Administration
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Huntsville, AL 35812
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11950 Jollyville Road
Austin, TX 78766

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APPENDIX IV

MATERIALS, COMPONENTS AND METHODS

This listing of articles and books pertains to sources and techniques applicable to high pressure.

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"Pressure Relieving Devices"
Chemical Engineering
Vol. 83, No. 11
(May 24, 1976)

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Erie, PA 16512

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ASTM, Part 41, Document #G-63

4. ASTM
"Metric Practice Guide"
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ASTM Standard E380-74 (1974)

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"Spring-Loaded Teflon or Graphite-Teflon Seal Design Manual"
Bal-Seal Engineering Company
Lahabra, CA
620 West Warner Avenue
Santa Ana, CA 92707
(714/557-5192)

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Chemical Engineering
February 5, 1973

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Pittsburgh, PA

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Chemical Engineering
Desk Book
(October 11, 1971)

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"Selecting Hand-Operated Valves for Process Plants"
Chem. Engr., June 14, 1982
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Product Engineering
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NBS Special Publication 326, P. 201
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Washington, D. C. (1971)

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"Pressure Vessel Closures"
Machine Design Notebook

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"Resilient Vessel Closures and Connections for High Pressure, Temperature Service"
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Autoclave Engineers, Inc.
2930 West 22 Street
P. O. Box 4007
Erie, PA 16512

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"Mechanical Packing and Piston Rings"
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France Products Division
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Vol. 83, No. 23 (October 25, 1976)

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Volume 30, No. 2 (February 1977)

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Research and Development
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Washington, D. C.

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   "Pressure Relieving Devices"
   Chemical Engineering
   Vol. 83, No. 11
   (May 24, 1976)

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   Erie, PA 16512

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   Bal-Seal Engineering Company
   Lahabra, CA
   620 West Warner Avenue
   Santa Ana, CA 92707
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   Chemical Engineering
   February 5, 1973

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Chem. Engr., June 14, 1982
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Petroleum Refiner
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Proceedings of the Compressor Technology Conference
(July 25-27, 1972)
Purdue University Press
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"Fluid Throttling Devices"
Product Engineering
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NBS Special Publication 326, P. 201
U. S. Government Printing Office
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Machine Design Notebook

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Technical Reprint 2751
Autoclave Engineers, Inc.
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P. O. Box 4007
Erie, PA 16512

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Catalogue 731
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Garlock, Inc.
Newton, PA

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"Compressor Valves and Components"
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