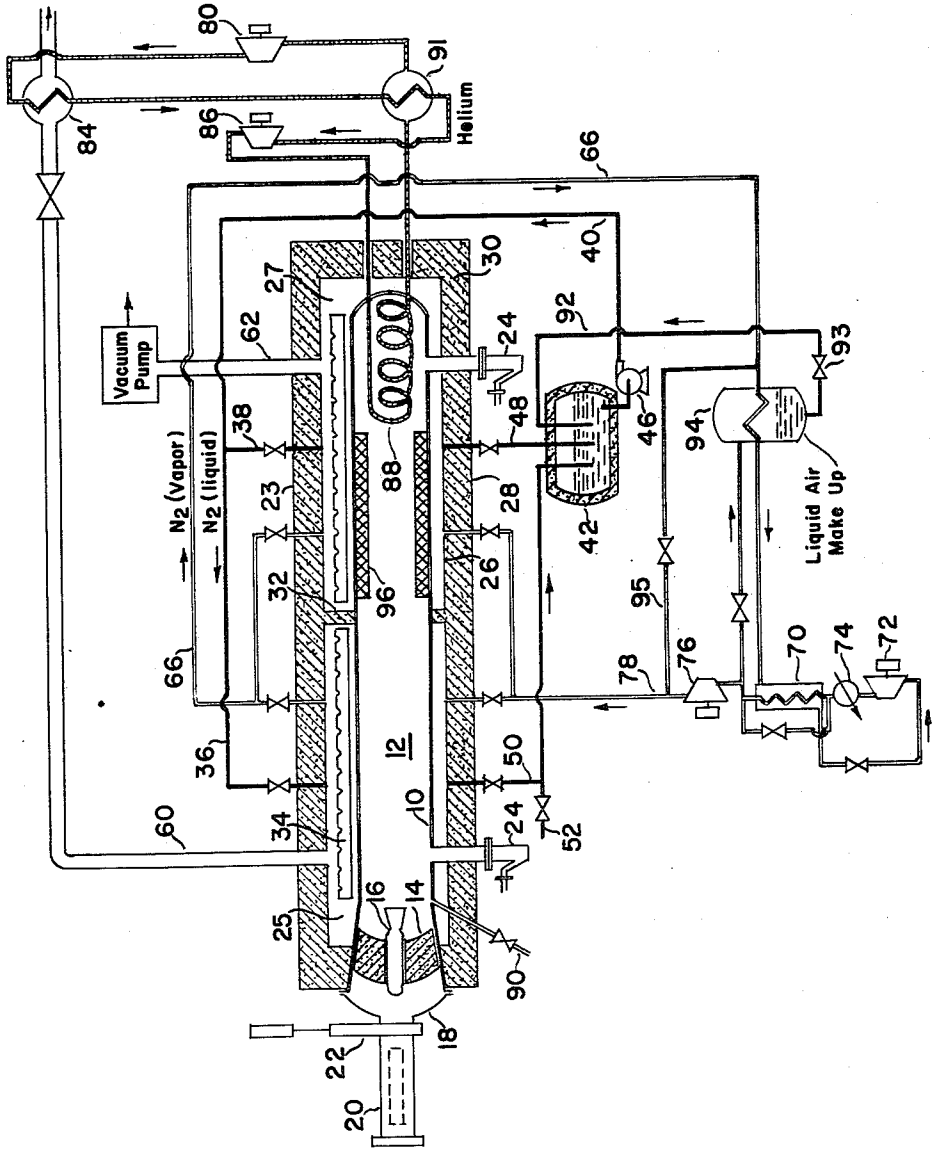
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HIGH VACUUM DEVICE

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HIGH VACUUM DEVICE

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This invention relates to testing and more particularly to apparatus for testing rocket motors and the like under conditions encountered by such rocket motors at extremely high altitudes.

In order to test rocket motors which are to be fired at high altitudes (well above the altitudes presently encountered by manned aircraft) it has been necessary to fire the rocket from another rocket or ballon and to telemeter test data back to the ground. There have been some attempts to fire such rocket motors under simulated conditions of high altitude at ground level. So far as is known, such simulated firing at ground level has not been successfully accomplished under conditions approximating those existing in the upper atmosphere.

Accordingly, it is a principal object of the present invention to provide testing apparatus which will permit firing of a rocket motor under conditions simulating those existing at altitudes from seventy-five to one hundred and fifty miles.

Still another object of the invention is to provide a testing apparatus which is capable of pumping millions of cubic feet per minute of gases resulting from the operation of a rocket motor in a high vacuum chamber.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the apparatus possessing the construction, combination or elements and arrangement of parts which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing which is a diagrammatic, schematic, sectional view of a preferred embodiment of the invention.

When firing a rocket motor under conditions corresponding to an altitude of seventy-five to one hundred miles, it is necessary to maintain a pressure on the order of 10^{-5} to 10^{-6} mm. Hg abs. The test system must be capable of handling the enormous volume of low-pressure gas generated when the rocket is fired into an evacuated chamber.

In a preferred embodiment of the invention, this is accomplished by providing an elongated vacuum-tight chamber which includes a means for evacuating the chamber to a free air pressure of less than 1 mm. Hg abs. It also includes a means for holding the rocket motor to be tested adjacent the forward portion of the chamber in a position to introduce the combustion products into the chamber at high velocity in a direction generally parallel to the axis of the elongated chamber. Adjacent that forward portion of the chamber holding the rocket motor, there is provided a first condensing surface which, in a preferred embodiment, is the wall of the elongated chamber. Refrigerating means is associated with this first condensing surface which is capable of maintaining this surface at a temperature on the order of 77° K. to

82° K. Further along the chamber there is provided a second condensing surface (also preferably part of the chamber wall) having an associated refrigerating mechanism for maintaining this surface at a temperature on the order of 65° K. Lastly, the chamber includes a third condensing surface and means for maintaining this third condensing surface at a temperature between 40° K. and 65° K.

The first condensing surface is preferably maintained at a temperature of about 77° K. to 82° K. by means of a supply of liquid air or nitrogen at atmospheric pressure which is sprayed over the outside of the chamber wall by means of a circulating pump and distribution system. Evaporation of the liquid air or nitrogen at atmospheric pressure will maintain this wall at about 77° K. to 82° K.

For covenience the invention will be initially described as employing liquid nitrogen. Accordingly, evaporation of liquid nitrogen at atmospheric pressure will maintain this wall at about 77° K. The second refrigerating surface is maintained at 65° K. by providing in contact therewith a supply of liquid nitrogen which is maintained at a pressure of about 200 mm. Hg abs., this pressure corresponding to a temperature of about 65° K. The third condensing surface is preferably maintained at the low temperature of between 4° K. and 65° K. by a refrigeration system utilizing gaseous helium. The gaseous helium refrigeration system preferably includes a compressor, counter-current heat exchanger, heat exchanger for utilizing cold nitrogen vapors and an expander. The helium refrigeration system is preferably maintained throughout the complete cycle at a temperature above the condensation temperature (4° K.) of helium so that it is not necessary to handle liquid helium.

The air or nitrogen system is preferably arranged so that during the initial cooling of the chamber from room temperature of about 300° K. to 77° K., total refrigeration duty of the expander is used for removal of most of the sensible heat in the system by a gaseous nitrogen recirculation system. Accordingly, the nitrogen system is arranged so that a closed compression-expansion cycle gradually reduces the temperature of the gaseous nitrogen by recycling to the point where it approaches the desired, extremely low temperature of nitrogen liquefaction. Thereafter, before the test rocket is fired the excess refrigeration produced by the expander can be used for liquefaction of air and fractionation of nitrogen and liquid nitrogen can be stored in an insulated container. During the actual rocket firing, when the heat load exceeds several times the expander duty, the accumulated inventory of liquid nitrogen is circulated to sprays or wiers and is used to supplement the expander duty.

Referring now to the drawing, there is shown a schematic, diagrammatic sectional view of one preferred embodiment of the invention. The apparatus comprises an elongated, stainless steel chamber **10** defining there within an elongated space **12**. Adjacent one end of chamber **10**, there is positioned an insulated plug **14** arranged to provide an effective heat break between test chamber temperature and room temperature and to support a rocket motor schematically indicated at **16**. The end of chamber **10** in front of plug **14** is at room temperature and is closed by a rubber gasketed vacuum door **18**. A valve **22** and a charging port are provided so that a sequence of rocket motors to be tested can be introduced into the space **12** after evacuation without disturbing the test chamber vacuum. A plurality of vacuum pumps **24** distributed along the length of the chamber are employed for evacuating space **12** to the requisite low pressure. In a preferred embodiment, these pumps include combinations of steam ejectors and diffusion pumps so as

to remove substantially all of the air from the interior of the chamber **10** as well as the noncondensible residue of combustion products near the point of first impingement of these noncondensible gases on the wall of the chamber **10**. While only 2 such pumps are shown, it is anticipated that as many as one hundred 16 inch high-vacuum diffusion pumps will be positioned along the chamber and around the periphery of a test chamber 12 feet in diameter and 100 feet long.

Outside of the chamber **10**, there is a double-walled insulating tank generally indicated at **23**. This insulating tank **23** has an inner wall **26** which is surrounded by a layer of insulation **30** and outer wall **28**. The space between walls **26** and **28** is preferably evacuated so as to improve the effectiveness of the insulation. A partition **32** extends from chamber **10** to wall **26** of insulating tank **23** so as to separate the space between wall **26** and chamber **10** into two separate volumes **25** and **27** which can be maintained at two different pressures. Wiers **34** and **35** are provided at the top of spaces **25** and **27**, respectively, these two wiers being fed liquid nitrogen from pipes **36** and **38**. Liquid nitrogen overflows from the wiers and covers the outer surface of test chamber **10** with a film of liquid. Liquid nitrogen vaporizing from the film into the spaces **25** and **27** provides a high heat transfer and maintains the inside walls of the test chamber **10** at the requisite low temperature corresponding to the nitrogen vapor pressure in the spaces **25** and **27**, respectively. The liquid nitrogen is fed through pipe **40** from a storage tank **42** by means of a recirculating pump **46**. Excess liquid nitrogen flowing around the sides of test chamber **10** is fed back to the storage tank **42** by means of drain pipes **48** and **50**. Makeup liquid nitrogen is introduced to the system by means of pipes **52** and **92**.

Nitrogen vapors at −320° F. (77° K.) escape from space **25** adjacent the front end of chamber **10** through pipe **60**, a compressed helium gas cooler **84** and then are vented to atmospheric pressure. The sensible heat of the vent gases at low temperature level can be used in regenerative heat exchangers, if economically desirable. Nitrogen vapors from the space **27**, adjacent the far end of the chamber **10**, escape from vent **62** which is preferably arranged, by means of vacuum pump **64**, to maintain a pressure on the order of 100 to 200 mm. Hg abs. in the space **27**, corresponding to nitrogen boiling points of 63° K. to 68° K.

While liquid nitrogen or liquid air can be utilized to cool the test chamber **10** from about 300° K. to 77° K., it is much preferred to utilize a gaseous nitrogen recycle system to remove most of the sensible heat. This system preferably includes a nitrogen vent **66** arranged to vent both chambers **25** and **27** during initial cooling of the system. During this initial cooling, these two chambers **25** and **27** preferably both operate at about atmospheric pressure. Nitrogen vapors in pipe **66** pass through a countercurrent heat exchanger **70** into a compressor **72** through an after cooler **74** and return back through the heat countercurrent exchanger **70**. Thereafter the compressed cooled nitrogen vapors are run through an expander **76** where the heat is removed as mechanical energy and the stream temperature drops 30° C. or more. From the expander the cooled gases are fed by means of pipe **78** back to spaces **25** and **27** to cool the chamber **10**, and the insulating tank **23**. Conventional means such as a reversing countercurrent heat exchanger or an adsorbent filter is used to avoid fouling of the countercurrent heat exchangers by ice or Dry Ice. (U.S. Patent No. 2,584,381, Dodge et al., February 5, 1952.)

The helium system includes a compressor **80** for compressing helium gas, and a heat exchanger **84** where the compressed helium gas is passed in heat-exchange relationship with cold (77° K.) nitrogen vapors passing through pipe **60**, after going through a countercurrent heat exchanger **91**, the chilled helium vapors are passed through expander **86** where further heat is removed as mechanical energy. The chilled helium vapors then pass through a condensing coil schematically indicated at **88** which is positioned inside of the test chamber **10** at the far end thereof from the rocket motor **16**. The cold helium will maintain the coil at a temperature between 4° and 65° K. Since the coil **88** is completely surrounded by cold (65° K.–77° K.) walls, it will pick up very little heat by radiation. Accordingly there is substantially no loss of refrigeration capacity of coil **88** due to radiation. If desired, liquid nitrogen or 65° K. nitrogen vapors can be used as refrigerant for the helium vapors.

In addition to the above-described pumping system, there is also preferably included an adsorbent mass **96**, preferably charcoal or silica gel, which is confined in a relatively thin layer around the periphery of the tank with a large exposed area to permit adsorption of noncondensible gases, such as hydrogen and nitrogen. This adsorbent mass **96** is chilled to 65° K. or thereabouts by the low temperature of the chamber **10** adjacent space **27**.

In the operation of the device as shown, steam is introduced to the interior of the test chamber **10** by means of a pipe **90**, the steam serving to displace air from the interior of the chamber and to heat the chamber walls to facilitate evaporation of moisture and other condensed vapors. While the steam is being introduced, the vacuum system is operated to continuously or intermittently remove a mixture of steam and air. When the inner surface of the walls of the chamber **10** have been heated to the requisite degree (e.g. 200° F.) and most of the air has been displaced from the interior of the chamber, introduction of steam is stopped and evacuation of the chamber proceeds by means of pumps **24**. During this evacuation, hot air or steam can be recirculated through the spaces **25** and **27** to maintain the chamber **10** at a relatively high temperature to degas the walls and remove any moisture and other volatiles. This high temperature also desorbs the adsorbent **96** so that it is activated to adsorb noncondensible gases.

When the vacuum pumps have reduced the pressure to about 0.1 mm. Hg abs., the cooling of the system is commenced. The nitrogen atmosphere in spaces **25** and **27** is recirculated through the pipe **66**, heat exchanger **70**, compressor **72** and expander **76** from which it is introduced back through the spaces **25** and **27**. Since this recirculation of nitrogen removes large quantities of heat from the spaces **25** and **27**, it will serve to cool the wall **10** of the test chamber, the inner wall **26** and the insulation **30** of the insulating tank **23**. By this means, the temperature of the walls **10** and **26** can be reduced to about 80° K. Thereafter the nitrogen vapor recycle system can be discontinued and liquid nitrogen is introduced through pipe **36** and **38** to wiers **34** and **35** so as to spray liquid nitrogen over the outer surface of test chamber **10**. In a short time, all of the sensible heat above 77° K. remaining in the test chamber **10** adjacent space **25** will be removed. Adjacent the space **27** all sensible heat in the chamber **10** above 65° K. will be removed due to the fact that the pressure in space **27** is maintained about 100 to 200 mm. Hg abs. corresponding to a temperature of about 65° K. The adsorbent **96** is also chilled to about 65° K. by heat exchange with wall of chamber **10**. The helium refrigeration system is brought into operation to bring the temperature of the condensing coil **88** down to a temperature substantially below 65° K., but above 4° K. A suitable rocket motor is placed in the charging port **20**, which charging port is evacuated. The rocket is then introduced into the holder **14** and is fired. The gaseous products of combustion pass down the space **12** and condense on the inner surface of chamber **10**. Some of the products of combustion will condense near the rocket motor where the wall surface

is about 77° K. Most of the remainder of the reaction products will condense at the far end of the chamber which is maintained at 65° K., while carbon monoxide and nitrogen will condense at the surface of cooling coil **88** which is maintained between 4° K. and 65° K. Hydrogen and helium in the reaction products will be pumped out by a multiplicity of ports distributed along the chamber the vacuum pumps **24**, backed by suitable forepumps.

Some of the hydrogen, helium and nitrogen will also be adsorbed by the very cold adsorption medium **96** so as to decrease the pumping load on the pumps **24**.

The gaseous nitrogen recycle system can be employed as part of the facility in manufacturing liquid air or liquid nitrogen during times when it is not required for cooling the chamber **10**. In this case, cold gas coming from the expander **76** can be passed through pipe **95** to heat exchanger **94** where it cools the interior of the heat exchanger to liquid air or liquid nitrogen temperatures. It then passes through the counter-current heat exchanger **70**, through the compressor **72**, the after cooler **74**, through the heat exchanger **70** again and a portion of the high pressure gases are then diverted to the heat exchanger **94** where liquid air or liquid nitrogen is condensed. The remainder of the stream passes through the expander **76** for removing further heat. If the system is operated at atmospheric pressure at the outlet of the expander **76**, liquid air will be produced in the heat exchanger **94**. If it is operated at sub-atmospheric pressure, liquid nitrogen can be condensed in condenser **94**.

Numerous changes in the above apparatus can be made without departing from the spirit of the invention. For example, sprays can be used instead of wiers **34** and **35**. Equally the refrigeration cycle can be modified by including high pressure systems as well as low pressure systems.

Since certain changes can be made in the above method and apparatus without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, or shown in the accompanying drawings, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Testing apparatus comprising an elongated vacuum-tight chamber, means for evacuating said chamber to a pressure less than 1 mm. Hg abs., means for positioning a rocket motor adjacent the forward portion of the chamber in position to introduce its products of combustion into the chamber at high velocity, first refrigerating means for maintaining a first condensing surface in the chamber at a temperature on the order of 77° K., said first condensing surface comprising a surface adjacent the forward portion of said chamber, second refrigerating means for maintaining a second condensing surface in the chamber at a temperature on the order of 65° K., said second condensing surface comprising a surface adjacent the backward portion of said chamber, and third refrigerating means for maintaining a third condensing surface in the chamber at a temperature between 4° K. and 65° K, said third condensing surface comprising a coil positioned within the backward portion of said chamber.

2. Testing apparatus comprising an elongated vacuum-tight chamber, means for evacuating said chamber to a pressure less than 1 mm. Hg abs., means for positioning a rocket motor adjacent the forward portion of the chamber in position to introduce the vapors therefrom into

the chamber at high velocity, a first refrigerating means for maintaining a first condensing surface in the chamber at a temperature on the order of 77° K., said first condensing surface comprising a surface adjacent the forward portion of said chamber, second refrigerating means for maintaining a second condensing surface in the chamber at a temperature on the order of 65° K., said second condensing surface comprising a surface adjacent the backward portion of said chamber, and third refrigerating means for maintaining a third condensing surface in the chamber at a temperature between 4° K. and 65° K., said third condensing surface comprising a coil positioned within the backward portion of said chamber, said first refrigerating means including means for providing a supply of liquid nitrogen at about 760 mm. Hg. abs., and said second refrigerating means including means for providing a supply of liquid nitrogen at about 200 mm. Hg abs.

3. The apparatus of claim 2 wherein the third refrigerating means includes means for compressing helium and removing heat from the compressed helium by heat exchange with nitrogen vapors in one of said other refrigerating means.

4. The apparatus of claim 2 wherein one of said first two refrigerating means includes means for flowing a thin layer of liquid nitrogen over the outer surface of the chamber-defining wall.

5. The apparatus of claim 2 wherein said first refrigerating system includes means for compressing nitrogen, means for expanding the compressed nitrogen to do work and remove heat therefrom and means for passing the expanded nitrogen in heat exchange relation to the first condensing surface to cool the first condensing surface.

6. The apparatus of claim 2 wherein means are included for introducing a condensible vapor into the chamber to displace non-condensible and atmospheric gases from the chamber and thus facilitate initial pump down of the system to a relatively high vacuum on the order of the few microns or less Hg abs.

7. The apparatus of claim 2 wherein the first condensing surface is nearer to the source of vapors than is the second or third condensing surface.

8. The apparatus of claim 2 wherein the third refrigerating means includes means for compressing helium and removing heat from the compressed helium by heat exchange with nitrogen vapors.

9. The apparatus of claim 2 wherein an adsorbent medium is positioned, in heat exchange relation to the cold chamber walls, inside of the chamber in position to adsorb large quantities of gases at low absolute pressures and temperatures.

10. The apparatus of claim 9 wherein the adsorbent is supported as a cylinder around the inner periphery of the chamber.

11. The apparatus of claim 2 wherein a plurality of diffusion pumps are distributed along the chamber to pump non-condensibles so that the non-condensibles will be pumped out of the system near the point of first impingement thereof on the chamber wall.

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