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Sauer

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[54] **HEAT EXCHANGER WITH ADJUSTABLE CONDUIT TRANSIT SIZE FOR CARRIER**

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[52] **U.S. Cl.** **165/96,** 62/45, 62/514

[51] **Int. Cl.** **F28f 27/00**

[58] **Field of Search** ..62/514, 45; 165/140, 141, 145, 165/96

[56] **References Cited**
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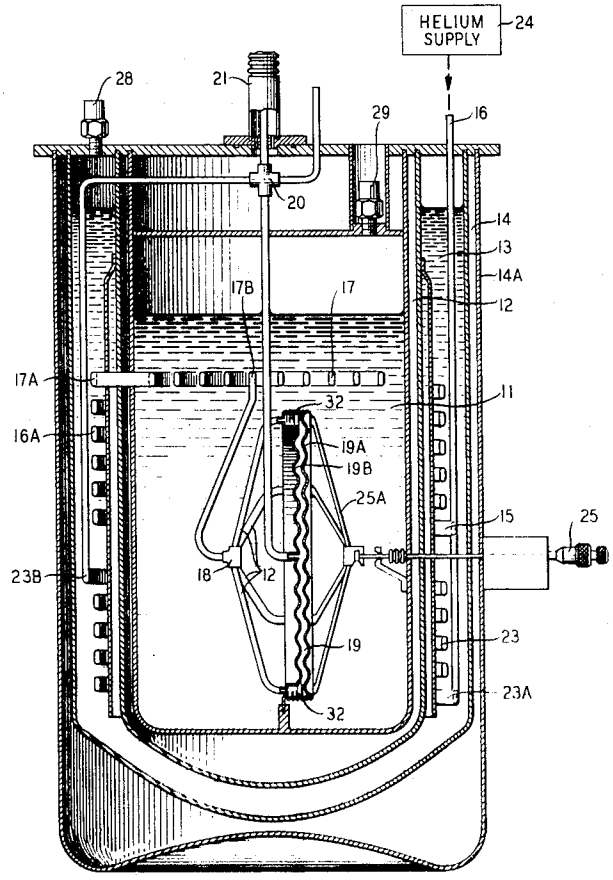
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[57] **ABSTRACT**

In a heat exchanger employing either a liquid or a gas carrier and particularly adapted for operation in the cryogenic range, efficiency is markedly enhanced and a simple means of temperature programming and control is provided by the use of a heat exchanger conduit with a rectangular cross section together with a means for adjusting the conduit transit width.

12 Claims, 2 Drawing Figures

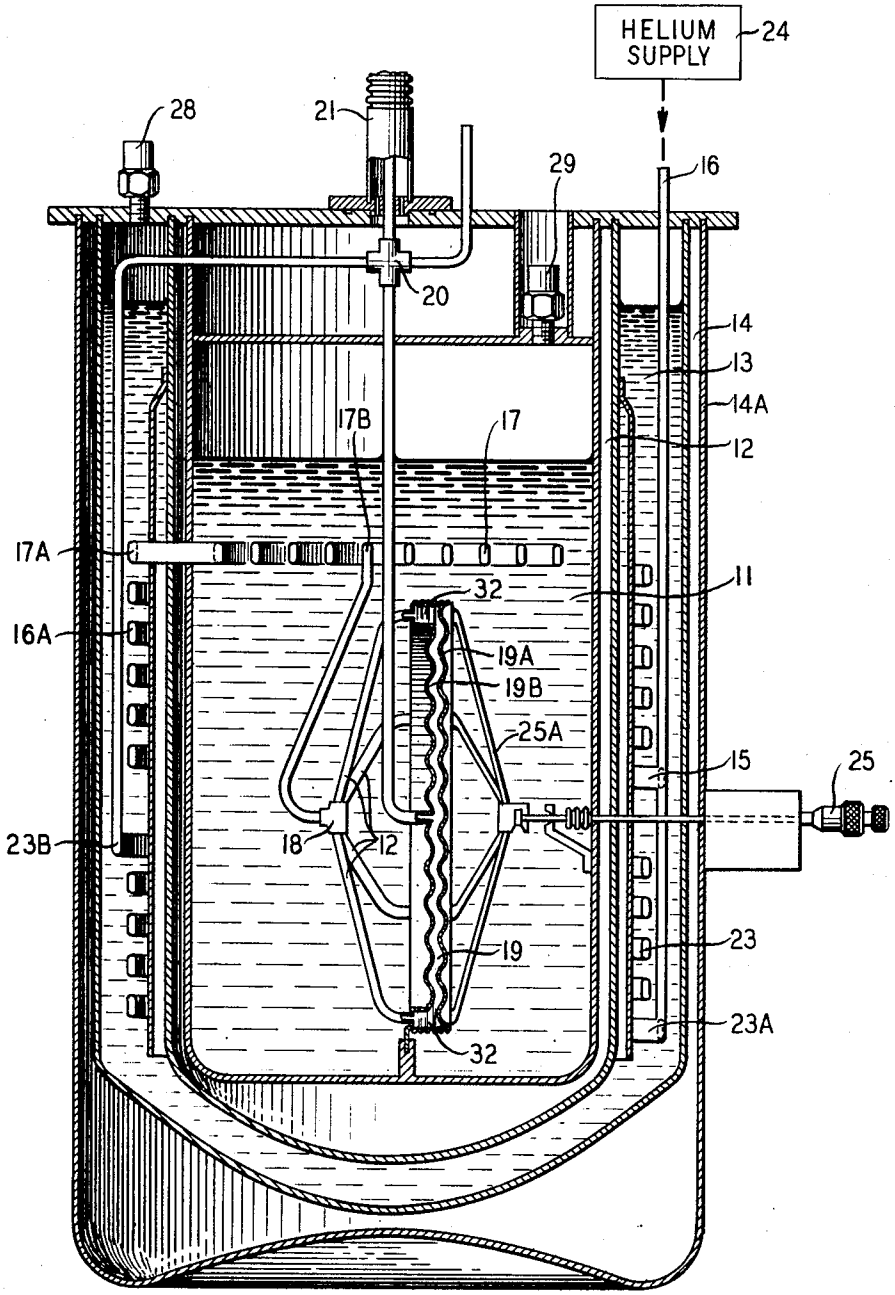


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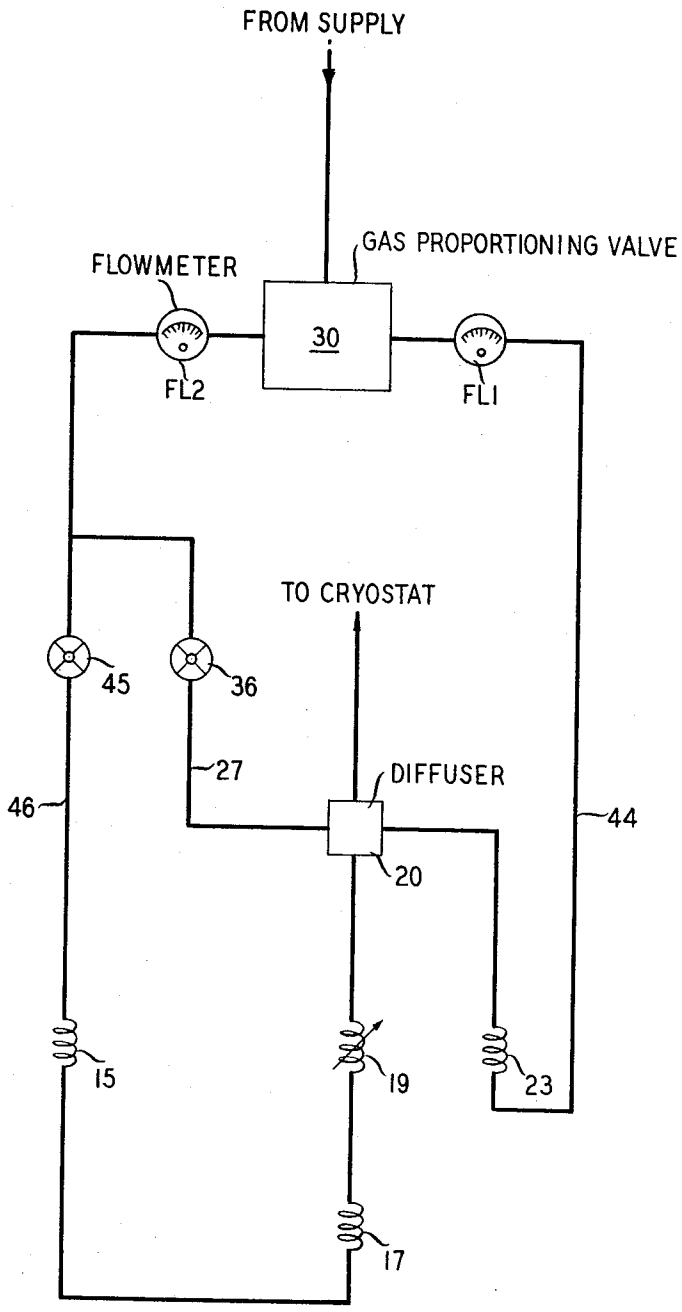
SHEET 1 OF 2

FIG. 1



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FIG. 2


FROM SUPPLY
GAS PROPORTIONING VALVE
FLOWMETER
30
FL2
FL1
TO CRYOSTAT
45
36
27
DIFFUSER
46
44
20
15
19
23
17

HEAT EXCHANGER WITH ADJUSTABLE CONDUIT TRANSIT SIZE FOR CARRIER

BACKGROUND OF THE INVENTION

I. Field of the Invention

This invention relates to heat exchangers primarily but not exclusively employed for supplying gas, such as helium at selected temperatures, generally within the cryogenic range.

2. Description of the Prior Art

The increasingly widespread utilization of heating and cooling sources in modern industrial plants and laboratories has created a growing demand for more efficient heat exchangers and for heat exchangers that are subject to precise control over wide ranges of temperature. Temperature control systems and heat exchangers of the type indicated find use in particular in the heating and cooling of specimens associated with instrumentation work employing, for example, spectrophotometers, microscopes, high frequency dielectric measurement apparatus, thermal diffusivity, specific heat facilities and X-ray equipment. Additionally, convenient and closely controllable cooling sources are required for laboratory work with cryogenic apparatus.

Although efficiency is a desirable characteristic in any heat exchanger, for heat exchangers operating in the cryogenic range the attainment of the maximum possible efficiency is a critical need if the system is to perform its designed function. One known phenomenon that has a distinctly adverse influence on prior art heat exchangers of the type indicated is identified as the Langmuir-Rice effect. Briefly, this effect is characterized by a stagnant or nearly stagnant film which adheres to a heat exchanger conduit surface when a fluid flows over that surface in laminar or turbulent flow. A full discussion of this concept is found in the text "Principles of Heat Engineering" by N. P. Bailey, pp. 79–95, John Wiley and Sons Inc., New York, N.Y., 1942. The existence of the Langmuir-Rice film or laminar sublayer has not only been experimentally demonstrated, but its thickness has been found to be dependent upon the fluid viscosity and density and upon the velocity of flow. In forced convection from the conduit wall to the main turbulent body of the fluid, this film impedes heat transfer to a degree that has been found to be specifically related to the thickness of the film, the temperature gradient across it and the specific heat and thermal conductivity of the fluid. More succinctly, the stagnant film conductance per unit area is the fluid thermal conductivity divided by the film thickness. Despite considerable detailed knowledge in the prior art concerning the nature and theory of the Langmuir-Rice films, however, no fully satisfactory means have been devised to overcome fully or to mitigate substantially the related reductions in heat exchange efficiency.

Accordingly, a general object of the invention is to improve the efficiency of heat exchangers. A more specific object is to limit the reduction in efficiency caused by Langmuir-Rice films.

SUMMARY OF THE INVENTION

The stated objects and additional objects are achieved in accordance with the principles of the invention by a fluid heat exchanger, primarily but not exclusively for supplying heat at selected temperatures within the cryogenic range, that employs an adjustable width heat exchanger conduit that is substantially rectangular in cross section, the height thereof being a relatively small fraction of the width. A heat exchanger in accordance with the invention is especially but not exclusively applicable to heat transfer by gas carriers and, as indicated, to helium in particular. The design is directed toward effecting significant economies in the use of both liquid and gaseous fluids, such as helium, and toward providing markedly higher efficiency in heat transfer than is obtainable in heat exchanger designs employing conventional fixed circular conduits.

The principles of the invention derive in part from exploiting the known principle that the most efficient heat transfer between a heat exchanger fluid and a conduit wall is achieved when the unit area film conductance has the highest attainable value. This condition may of course be established by increasing the velocity of a flow which advantageously decreases the film thickness. For a fixed rate of mass transfer, the velocity is advantageously increased, in accordance with the invention, by reducing the cross sectional area. The cross sectional area, however, cannot be decreased at the expense of conduit surface area if the total heat transfer is to remain high. In accordance with the invention, therefore, a large conduit surface area is retained by employing a rectangular configuration of high aspect ratio. As a result, the major surfaces of the conduit are brought into close proximity.

For conduit sizes and fluid flows usually encountered in practice, calculations indicate that the Langmuir-Rice film thickness may range to 0.010 inches and higher. Transit widths of this dimension and even several times larger have been found to increase heat transfer markedly because of the virtual elimination of the stagnant layer in turbulent flow. When the long side of the rectangular transit cross section is fixed, for a predetermined rate of mass transfer of a particular fluid at a specific pressure, it can be shown, experimentally, that there is an optimum transit width and a minimum length of transit path to provide the most efficient heat exchange between the conduit wall and fluid. In practice, the length of the path is usually adequate to span a wide range of flow and pressure to attain maximum efficiency. Owing to the low thermal conductivity of gases, their film heat transfer coefficients are appreciably lower than for liquids. The specific heat of gases such as nitrogen and helium is quite high in the cryogenic region, increasing with decreasing temperature. In contrast, the thermal conductivity decreases with a reduction in temperature. This fact, combined with the fact that the viscosity of gases decreases with a reduction in temperature, is of particular significance in the design of a heat exchanger in accordance with the invention, particularly when employing gas carriers in the cryogenic range. In fully developed turbulent flow, the proximity of the major heat exchange surfaces, combined with the temperature dependence of these thermodynamic and transport properties, statistically greatly increases the frequency of impact of gas molecules with these surfaces, which is to say that heat exchange is enhanced. Accordingly, the heat transfer becomes more importantly related to the high specific

heat and viscosity of the gas than to the remanent stagnant film and the poor conductivity. It should be emphasized that, significantly, by virtue of the dynamics of heat transfer and in accordance with the philosophy indicated, the effect of high heat-leaks at the lowest temperatures tends to be neutralized by the mobility, turbulence and by the specific heat of the gas.

In accordance with an important feature of the invention, the smaller dimension of the indicated rectangular heat exchanger conduit is made adjustable. As a result, an optimum dimensional ratio for the most efficient heat transfer under a variety of conditions is readily available. A second useful function that flows from the adjustability feature is that a simple means of temperature programming and control is made available in applications where gas pressure and the rate of maximum transfer are not critical. Using the adjustability feature, in accordance with the invention, makes possible temperature programming down to very low cryogenic temperatures.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a sketch partially in cross section of a heat exchanger in accordance with the invention; and

FIG. 2 is a schematic diagram of the paths followed by the temperature controlled medium in a heat exchanger of the general type shown in FIG. 1.

DETAILED DESCRIPTION

As a preface to a detailed structural description of the heat exchanger shown in FIG. 1, a general statement of its operation may be useful. Helium gas which is precooled in a rectangular conduit in liquid nitrogen is passed through a rectangular conduit of fixed cross section situated in a reservoir of liquid helium. The gas then passes into an adjacent conduit of adjustable transit width also located in the liquid helium reservoir. The temperature conditioned helium gas is then made available through a helium transfer line for cryogenic applications.

The heat exchanger structure shown in FIG. 1 is a multiwalled dewar chamber. The innermost compartment **11** is a liquid helium reservoir. This reservoir is thermally insulated by a vacuum jacket **12**. Encasing the vacuum jacket **12** is a liquid nitrogen reservoir **13**. The nitrogen reservoir **13**, in turn, is encased in a vacuum jacket **14** which also furnishes the outer surface **14A** of the exchanger. A copper conduit **15** of rectangular configuration with fixed transit dimensions is wound in helical coil form and is located in the nitrogen reservoir **13**. The entry end **16** of the coil **15** is connected to a helium gas supply **24** at ambient temperature. The exit end **16A** of the helically wound rectangular conduit **15** is connected to the entry end **17A** of a copper conduit **17** of rectangular configuration with fixed transit dimensions, spirally wound and positioned in the helium reservoir **11**. The exit end **17B** of the spiral conduit **17** is connected to an entry manifold **18** of a copper conduit **19** which has a substantially circular configuration and an adjustable transit width. The major circularly corrugated circular plates **19A** and **19B** of the conduit **19**, supported by a bellows cylinder **32**, are positioned with respect to each other in such a manner as to form an adjustable gas transit with sinusoidal undulations extending from the periphery to the center at which point the gas is directed to a diffuser **20** and exits from the exchanger via a standard helium transfer line **21**.

From the manifold **18** six copper tentacle-like conduits **12** (four of which are shown), each being of the same rectangular configuration as the coil **17**, are connected to the periphery of the disk conduit **19** and are spaced equally apart to provide more or less uniform distribution of the gas in its transit through the conduit.

A second independent copper conduit **23** of rectangular configuration with fixed transit dimensions and a helical coil form is also located in the liquid nitrogen reservoir **13**. The entry point **23A** of the coil **23** is also connected to the helium gas supply **24**. The exit end **23B** is connected to the diffuser **20**.

The top adjustable plate **19A** of the circular disk conduit **19** is driven from a micrometer **25** and a connecting yoke **25A**, thus providing a means for controlling transit width. The opposite plate **19B** is rigidly supported by the straight inside wall of the bellows **32**. It will be observed that the detailed conformation of the adjustable disk component **19A** takes into account the desirability for limiting, as much as possible, the pressure drop in the gas flow through this constricted transit.

In the transfer of heat in the heat exchanger to the boiling liquid helium and liquid nitrogen, helium gas bubbles and nitrogen gas bubbles form on the various heat exchanger surfaces. This action is termed "-nucleate pool boiling" and is described by A. J. Chapman in his text *Heat Transfer*, pp. 385–390, Second Edition, 1967, B. MacMillan Co., New York. In the liberation of these bubbles from the heat exchanger surfaces, turbulence is induced and film conductance, hence heat transfer is thereby increased. It is therefore imperative that the essential heat exchange components, namely the coil and disk conduits, be so oriented vertically, in accordance with the invention, in the cryogenic liquids so as to facilitate the continuous removal of these bubbles from the indicated surfaces. A high rate of formation of vapor bubbles can result in an accumulation of contiguous gas bubbles adhering to the surface, thus forming a substantial barrier to effective heat transfer. Such action may occur if a large temperature gradient exists between the heat exchange surface and the boiling liquid or if the liquid pressure is too low to prevent it. Provision is made, therefore, to adjust the pressure over the boiling cryogenic liquids.

In describing the operation of a heat exchanger in accordance with the invention in a way that involves programming from the lowest cryogenic temperatures obtainable up to room temperature, reference is made to the gas circuit schematic diagram of FIG. 2. As shown, the physical arrangement of the major heat exchanger elements is generally similar to that illustrated in FIG. 1, although certain modifications have been made and the mechanical details have been omitted. Corresponding elements in the two Figures bear common designating numbers. Ambient gas from the proportioning valve **30** enters at conduits **46** and **44**. The gas entering at conduit **46** is precooled in a liquid nitrogen reservoir as described above. Its temperature is lowered further as it passes through the spiral coil **15** in the liquid helium reservoir. In the narrow, adjustable, undulating transit **19** turbulence is increased and more gas molecules are

compelled to make more frequent contact with the conduit walls, and it is there that minimum gas temperatures are obtainable, assuming optimum levels of gas flow rate and pressure.

The gas entering by way of the entry path **44** is conditioned exclusively in a liquid nitrogen reservoir by the coiled rectangular cross-section conduit **23**. Both independent routes terminate in the diffuser **20** where gases of different temperatures are mixed. The flow rate ratio of the two routes, determined by the gas proportioning valve **30**, provides additional assurance that the desired temperature in the cryostat will be maintained. At the very lowest temperature obtainable, no gas flows into the diffuser **20** from the conduit **44**. In this very low temperature region it is advantageous to effect programming and control simply by manipulating the transit width of the adjustable conduit **19** as described above.

In the region of −200° C., the control action of the proportioning valve **30** is reversed. This shift is necessary since conduits **44** and **46** must exchange their specific functions in order to ensure proper control of both higher and lower temperature gas-flows to the diffuser **20**. Simultaneously, the solenoid valve **45** is closed and the solenoid valve **36** is opened. This action shuts off gas to the diffuser **20** coming from the liquid helium reservoir and admits ambient gas to the diffuser by way of a conduit **27**. Thus, uninterrupted temperature programming of the cryostat up to room temperature may be accomplished.

When the liquid nitrogen and liquid helium boil off, they are not utilized to reduce heat-leaks in the helium transfer line **21** (FIG. **1**). Instead, pressures above the boiling liquids are controlled by means of relief valves **28** and **29**. Flow velocity should be maintained as high as possible consistent with efficient heat transfer in order to reduce changes in the heat content of the carrier gas in its journey from the heat exchanger to the cryostat.

It is to be understood that the embodiments described herein are merely illustrative of the principles of the invention. Various modifications thereto may be effected by persons skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A gaseous medium heat exchanger comprising, in combination,

an insulated mantle surrounding a cavity portion for containing a first liquid coolant,

means for passing said medium through said coolant thereby to adjust the temperature of said medium,

said means comprising at least one conduit having a substantially rectangular cross section with an adjustable aspect ratio thereby to enhance the efficiency of heat transfer between said medium and said coolant and to facilitate a programmed control over the temperature of said medium.

2. Apparatus in accordance with claim **1** wherein the major walls of said conduit are substantially vertically aligned.

3. A gaseous medium heat exchanger comprising, in combination, an insulated mantle surrounding a cavity portion for containing a first liquid coolant,

a jacket portion for containing a second coolant positioned around said cavity portion,

a first conduit comprising a coiled tube, substantially rectangular in cross section, positioned within said jacket portion thereby to provide a means for precooling said gaseous medium,

a second conduit substantially rectangular in cross section positioned within said cavity portion,

means for adjusting the smaller dimension of said cross section of said second conduit,

means for directing said gaseous medium, after said precooling, from said first conduit to said second conduit,

and means for conducting said gaseous medium out of said exchanger after passage through said second conduit.

4. Apparatus in accordance with claim **3** wherein said second conduit comprises a pair of plates vertically aligned within said cavity and spaced to form a relatively narrow passage therebetween.

5. Apparatus in accordance with claim **4** including a bellows arrangement linking the outer peripheries of said plates,

said adjusting means being capable of exerting pressure to deform said bellows whereby one of said plates is brought into closer proximity with the other one of said plates.

6. A gas heat exchanger for supplying a gaseous medium at a preselected temperature comprising, in combination,

a first heat transfer conduit for said gaseous medium immersed in a first coolant,

a second heat transfer conduit for said gaseous medium immersed in a second coolant,

means for directing said medium from said first conduit to said second conduit,

at least one of said conduits having a substantially rectangular cross section with a relatively high aspect ratio and means for adjusting said ratio.

7. Apparatus in accordance with claim **6** wherein said one conduit comprises upper and lower spaced disk members in relative juxtaposition having a space therebetween for the passage of said gaseous medium, said disk members being vertically aligned.

8. Apparatus in accordance with claim **7** including mechanical means for adjusting the thickness of said space thereby to facilitate a programmed control over the temperature of said medium.

9. Apparatus in accordance with claim **8** wherein said mechanical means comprises a bellows member around the outer periphery of said disks, said lower disk being substantially immovable and affixed to the lower fixedly mounted portion of said bellows,

said upper disk being relatively movable and affixed around its periphery to the upper compressible portion of said bellows,

yoke means positioned for applying compressible force to the upper portion of said bellows,

and manually operable means for applying measured force against said yoke means.

10. Apparatus in accordance with claim **6** wherein said directing means comprises

first tube means extending from the discharge point of said first conduit to a manifold member,

a plurality of second tube means each extending from said manifold member to a respective point on the periphery of said disks,

and third tube means extending from the center portion of said space to an output point in said exchanger.

11. A gas heat exchanger for supplying a gaseous medium at a preselected temperature comprising, in combination,

a first conduit for precooling said gaseous medium, said conduit being substantially rectangular in cross section and being immersed in a first coolant,

a second conduit for final cooling of said gaseous medium, said second conduit being substantially rectangular in cross section and being immersed in a second coolant, and

means connecting the discharge of said first conduit to the input of said second conduit.

12. Apparatus in accordance with claim 11 wherein said first conduit comprises

a coiled tube and wherein said second conduit comprises a pair of vertically aligned disk members in spaced parallel relation,

means for directing the flow of said gaseous medium from the outer periphery to the center portion of the space between said disk members,

and means for conducting said gaseous medium from said center portion to an output point of said exchanger.

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