

[54] **MULTISTAGE VACUUM PUMPING SYSTEM**

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[58] Field of Search **417/68, 69, 243, 205, 62, 438**

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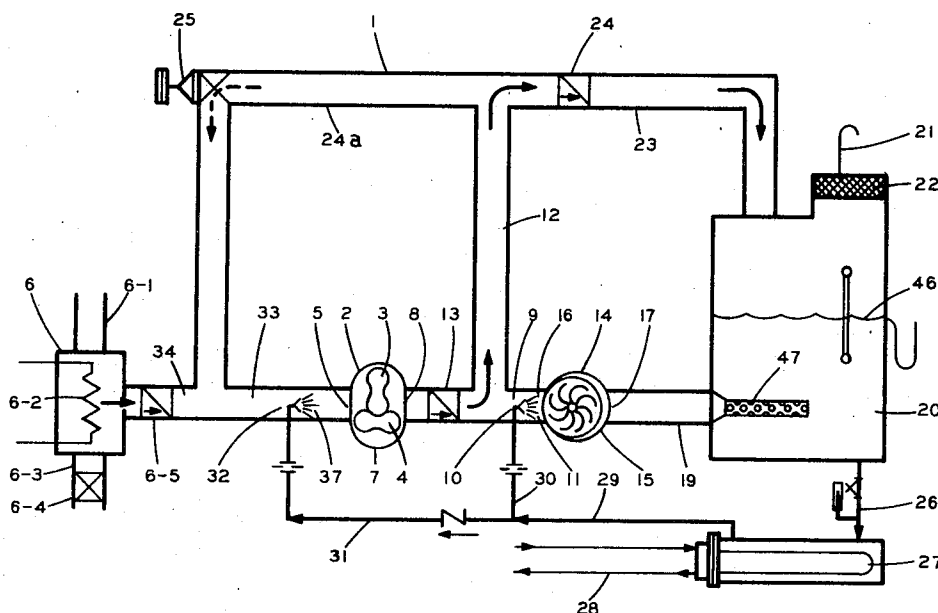
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[57] **ABSTRACT**

A self-regulating vacuum pumping system comprising a first stage positive displacement pump arranged in series with a second stage liquid ring pump. The high volumetric efficiency of the positive displacement pump is substantially improved by the combination compression, cooling and condensing action of the liquid ring pump.

13 Claims, 3 Drawing Figures



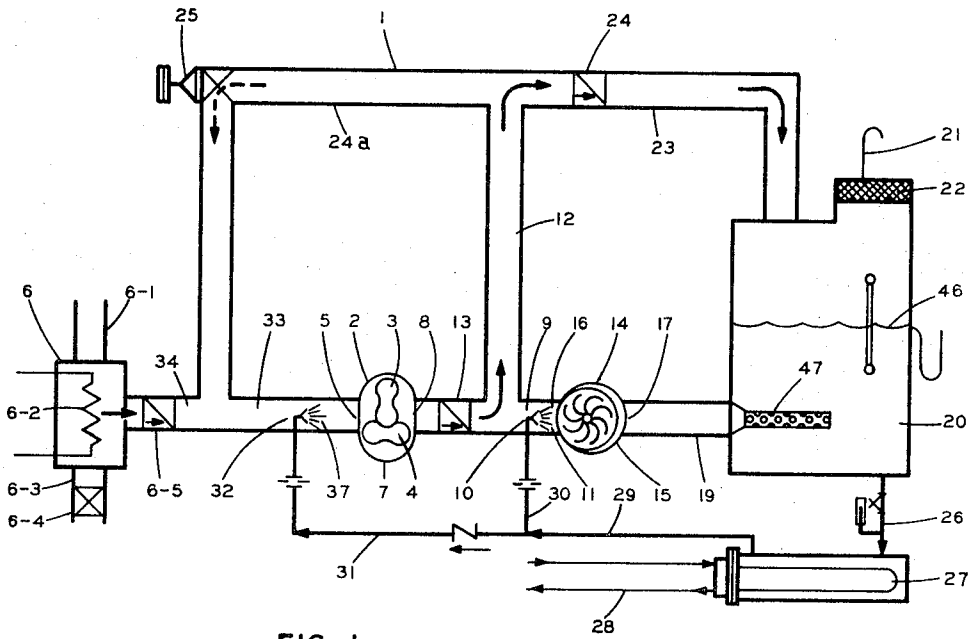


FIG. 1

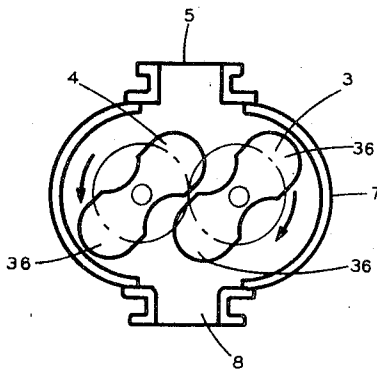


FIG. 2

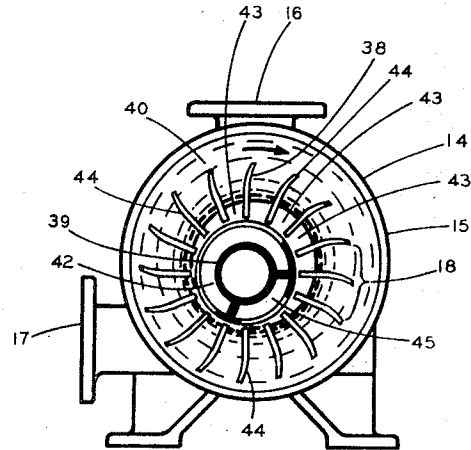


FIG. 3

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MULTISTAGE VACUUM PUMPING SYSTEM

BACKGROUND OF THE INVENTION

In the application of vacuum pumping apparatus to saturated vapor-gas systems, such as the exhaust from a condenser system in which it is desired to keep the temperature constant, and to achieve lowest possible pressure, it becomes increasingly difficult to obtain a deeper vacuum because the vapor pressure of the gases is ordinarily a limiting factor. As the partial gas pressure approaches zero, the resultant volume of the gases approaches infinity. Likewise, for a given weight of air or gas the volume of saturation vapor increases greatly as the partial air or gas pressure is decreased. The vapor pressure limitation is even more serious as the absolute pressure approaches the vapor pressure of the liquid in saturation. No way is presently known to extract the gas without removing the vapor. It is therefore necessary to provide an efficient means to extract the noncondensable gases, and to condense and separate the vapors from the gases.

FIELD OF THE INVENTION

The main condensers for steam turbine systems require high vacuum to realize maximum turbine efficiency. Other applications where a self-regulating vacuum pumping system is highly desirable include vacuum dryers, vacuum cookers, vacuum strippers for chemical reactors, sterilizers, autoclaves and rotary vacuum filters. When evacuating condensers, evaporators, dryers, and other systems where vapor is present it is necessary to remove not only the dry air component but the accompanying vapor component. This imposes a large volumetric load in the exhauster. Applicant's invention is particularly useful in such systems, which require the efficient handling of air-vapor mixtures.

DESCRIPTION OF THE PRIOR ART

Multistage steam ejectors have been used for producing vacuum in the main condensers of turbogenerator systems. However, such systems are difficult to automate, and are limited to extracting air-vapor mixtures on a constant weight basis. Large variations in the air-vapor volume may upset the jet equilibrium, causing loss of capacity. To avoid this, the apparatus is oversized. Water eductors have been used, but they are even less efficient.

Reciprocating, rotary piston, sliding vane and liquid ring vacuum pumps have also been used for condenser vacuum systems. Those which require lubrication cannot normally tolerate condensation during compression. The liquid ring vacuum pump is most desirable, because it is reliable, is a non-lubricated type of pump, and requires little maintenance. However, the liquid ring pump requires a substantial partial air pressure to operate efficiently and to avoid "cavitation" effects.

In the past, the liquid ring pump has been coupled with an air ejector to provide a means for raising the vacuum into the desired high vacuum range. In such a system, the air removal efficiency is low and the power requirements are high. For every pound of noncondensable gases extracted, the system must handle about three pounds of motive air, thereby requiring a substantially oversized liquid ring pump for the second stage of the system.

A combination of a first stage liquid ring pump with a second stage centrifugal pump has also been suggested. This combination, however, is intended primarily to handle large quantities of liquid with some entrained gases and vapors. In this combination, flooding of the liquid ring pump is not avoided, and the system merely uses the centrifugal pump to improve the water handling characteristics of the liquid ring pump. Such operation offers no increase in volumetric efficiency, and there is no means for avoiding prolonged marginal operation of the liquid ring pump. In the flooded condition, the centrifugal pump is, in effect, pulling the liquid through the liquid ring pump. The centrifugal pump does not increase the actual volumetric efficiency of the liquid ring pump but

merely prevents it from overloading and stalling the common drive motor. In such an arrangement, the centrifugal pump is necessarily oversized.

SUMMARY OF THE INVENTION

This invention is directed to the combination of a rotary positive displacement vacuum booster pump as the first stage of a vacuum pumping system and a liquid ring vacuum pump second stage. The system provides high volumetric efficiency over a wide operating vacuum range with low power requirements. The system is compact, inherently self-regulating, and the rotary components require no lubrication, since there is no metal-to-metal contact in either the first stage, lobe-type positive displacement vacuum booster pump, or in the second stage liquid ring pump. The rotary positive displacement pump selected is of normal size for the operating capacity required, and its volumetric efficiency is substantially increased by the second stage liquid ring pump. The advantages of both types of pumps are more fully realized in the integrated, thermodynamically balanced system provided by the invention.

The two types of pumps provide an ideal combination for series operation and for handling liquid entrained with the pumped fluid, as well as liquid condensed during compression. The first stage pump is capable of compressing saturated vapor-gas mixture in a ratio of as much as eight to one. The heated and saturated vapor-gas mixture may then be cooled by a water spray in between the first and second stage pumps. The mixture is then pulled into the second stage liquid ring pump where the saturated vapor-gas mixture is further cooled and compressed, with further condensing of the vapor component of the mixture to substantially increase the capacity of the second stage liquid ring pump. Although, the system finds best use for pumping saturated vapor-gas mixtures, it can also be used for pumping of dry gases.

A control means is also provided so that the first and second stages of the vacuum pumping system are automatically stabilized to insure efficient operation over a full vacuum range. The first stage displacement is always kept in balance with second stage capacity by means of automatically operated by pass controls.

This invention makes use of the uniquely desirable features of positive displacement pumping device as a first stage pump backed by a liquid ring centrifugal displacement second stage pump. The thermodynamic relationship between these pumps provides optimum efficiency, especially when handling saturated fluids at low absolute pressure.

The thermodynamic interaction of the two types of pumping means, that provides the outstanding performance and high efficiency that may be achieved with the pumping system described. The first stage rotary positive displacement pump has exceptionally high volumetric efficiency when operating with low pressure differential. The liquid-ring second stage pump has the ability to act as a condenser, thus reducing the volume of the vapor component.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 of the drawings is a schematic illustration of a multistage vacuum pumping system according to the invention;

FIG. 2 is an enlarged side sectional view of the positive displacement first stage pump shown in FIG. 1;

FIG. 3 is an enlarged side sectional view of the liquid ring second stage pump shown in FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

The vacuum pumping system 1 includes a first stage, rotary positive displacement vacuum booster pump 2. The pump 2 is a lobe type, positive displacement rotary pump of the Roots type which includes two counter-rotating rotors 3 and 4 matched to rotate together to trap and pump a fixed volume of a saturated vapor-gas mixture discharged into pump inlet 5

from a condenser 6. Condenser 6 may include an inlet 6-1, which receives exhaust fluid from a system under vacuum. The system may also include heat transfer means such as condenser coils 6-2, a drain 6-3, and a drain control valve 6-4. An inlet check valve to the vacuum pumping system 1 is also shown. The condenser 6 may, of course, be arranged so that only a gaseous mixture is transferred through the inlet control valve 6-5 to the vacuum pumping system 1.

Alternately, the arrangement permits liquid plus gaseous fluids to be handled by the vacuum pumping system 1. The saturated vapor gas mixture is displaced as it is carried through casing 7 and discharged at outlet 8. This pumping action is repeated four times per revolution of each rotor 3 and 4. The rotors 3 and 4 rotate without contact, but with close clearances, to attain maximum volumetric efficiency.

The saturated vapor-gas mixture increased in temperature and pressure as it is compressed by the pump 2. The compressed saturated vapor-gas mixture passing through outlet 8 then normally passes through an interstage cooler 9, which may take the form of a water spray nozzle 10 disposed in conduit 11. An interstage bypass conduit 12 branches off from the conduit 11 downstream from the pump 2. A check valve 13 may be installed in conduit 11 to prevent backflow during shutdown, conduit 12. A second stage liquid ring pump 14 is connected to the pump 2 by conduit 11 downstream from the interstage cooler 9.

The liquid ring pump 14 includes an eccentric casing 15, an inlet 16, an outlet 17 and a rotor assembly 18, shown schematically in FIG. 1. The outlet 17 connects through conduit 19 to a separator tank 20. The upper end of the separator tank 20 includes a vent 21 to atmosphere. An entrainment separator screen 22 is normally disposed across vent 21.

A bypass conduit 23 interconnects the interstage bypass conduit 12 to the upper portion of the separator tank 20. A pressure regulated check valve 24 is disposed in conduit 23 to control direct flow to the separator tank 20 from the positive displacement pump 2. A recirculation conduit 24^a is also connected to the interstage bypass conduit 12. The recirculation conduit 24^a interconnects the outlet 8 of the positive displacement pump 2 to its own inlet 5. A pressure relief valve 25 is provided in conduit 24^a to limit the pressure in the recirculation loop to the designed operating pressure range of the pump 2.

The pressure relief valve 25 is adjustable, and is used to control the differential pressure across the first stage positive displacement pump 2. The relief valve 25 effectively reduces the power requirement for the system because the power requirements in the first stage (booster) pump 2 is a direct function of pressure differential, and the valve 25 keeps the power requirements low by limiting the pressure differential across the pump 2. This is particularly important during startup (pull-up) when the vacuum pumping system 1 commences operation. The relief valve 25 insures that the positive displacement pump will not be subjected to an excessive load, and permits sizing the first stage pump for a larger staging ratio.

The separator tank 20 is also provided with a sealing water conduit 26 which recirculates sealing water through a heat exchanger 27 provided with cooling water through cooling water tubes 28. A sealing water feed conduit 29 supplies water to the interstage cooler 9 through branch 30. A second branch 31 may be included to supply water to a second cooler 32 which is disposed in suction intake conduit 33 of the vacuum pumping system 1. As shown, the suction intake conduit 33 is connected to exhaust conduit 34 of a condenser 6 in a steam turbine system.

The main components of the system are the first stage positive displacement pump 2, the second stage liquid ring pump 14, the separator tank 20 and the heat exchanger 27. The pumps 2 and 14 are driven by any suitable drive means, such as an electric motor. The pumps 2 and 14 may be driven by individual motors, or a single motor can be used to drive both.

The rotors 3 and 4 of the first stage positive displacement pump 2 are matched to counter rotate freely with substantially

no metal-to-metal contact, driven by a motor (not shown) connected to the rotor 3. The saturated vapor-gas mixture from the condenser 6 is trapped by intermeshing lobes 36 of the rotors 3 and 4, compressed, and then discharged through outlet 8 into interstage conduit 11. A water spray cooler 37, similar to the interstage cooler 9, injects sealing water into the inlet 5 of the pump 2 to seal the clearances between the lobes 36, and to aid in cooling the pump 2, which is heated by the rising temperature of gases being compressed therein.

The second stage liquid ring pump 14 has only one moving part, a vaned rotor 38, which is part of the rotor assembly 18. As can be seen in FIG. 2, the vaned rotor 38 which is driven by the motor rotates freely around a stationary port cylinder 39. The rotor 38 and the port cylinder 39 are concentric, but the casing 15 has an eccentric volute 40 formed therein. Sufficient sealing water is supplied through interstage cooler 9 to the liquid ring pump 14 to form a liquid ring 41 inside the casing 15 conforming to the eccentric contour of the casing 15. As can be seen in FIG. 2, the port cylinder 39 is provided with an inlet port 42 radially inward from the portion of liquid ring 41 as it is receding away from the port cylinder 39, thereby defining chambers 43 between adjacent rotor vanes 44 for receiving the saturated vapor-gas mixture from the inlet 16. As rotation continues, the chambers 43 enlarge to a maximum, and then decrease as the rotating liquid ring 41 is guided closer to the port cylinder 39 by the eccentric casing 15. An outlet port 45 is disposed on the port cylinder 39 radially inward from the portion of the liquid ring 41 which is advancing closer to the port cylinder 39. In this manner, the rotor vanes 44, in cooperation with the liquid ring 41, pump the saturated vapor-gas mixture through the pump 14, the liquid ring 41 serving both to further compress the vapors and noncondensable gases, and to cool the mixture to further reduce the volume by condensing the vapors.

The liquid ring pump 14 discharges through discharge conduit 19 into the separator tank 20. The discharge conduit 19 normally enters the tank 20 below the liquid level 46, and is provided with a perforated end extension 47 to better distribute the now substantially condensed vapors and noncondensable gases. The gases bubble up to escape through the vent 21 to the atmosphere. The separator tank 20 serves both as a reservoir for seal water for pumps 2 and 14, and as a gas separator for the compressed gas-condensed vapor mixture discharged from pump 14 as well as silencer.

The heat exchanger 27 further cools the condensate which is used as seal water in the pumps 2 and 14. Raw water, or any other readily available cooling liquid, may be used as the cooling medium, and is normally pumped through the tubes 28 at a rate to obtain the optimum operating temperature.

The thermodynamic interaction of the combination pumping system is a most significant feature of the invention which can be illustrated by a specific example. A first stage, positive displacement pump is employed which is designed to handle 60 lb./hr. dry air plus water to saturate at 84° F. (1,260 cubic feet per minute input volume) with input pressure of 1.5 in. Hg absolute. The first stage pump is coupled with a second stage liquid ring pump which can handle an input volume of 212 cubic feet per minute at 94° F., and input pressure is 3.5 in. Hg absolute.

For this combination, the first stage pump recorded an outlet pressure of 3.5 in. Hg, outlet temperature was 109° F., and the output volume was reduced to 438 cubic feet per minute giving a compression ratio in the first stage of about 2.33 to 1. The partial air pressure at the inlet to the first stage was 0.325 in. Hg, and the outlet partial air pressure was 0.979 in. Hg, giving a ratio of 5.8:1 on partial air pressure for the first stage. The air being handled through the system remained constant at 1 lb. per minute through both stages.

The water vapor volume entered the first stage at a rate of 2.24 lbs. per minute, and left the first stage at a rate of 1.60 lbs. per minute effecting a condensation rate of 0.64 lbs. per minute.

The interstage cooler 9, for the example given, cooled the saturated vapor-gas-liquid mixture from the first stage pump from 109° to 94° F., reducing the partial vapor pressure from about 2.52 in. Hg to 1.61 in. Hg. The partial air pressure increased from about 0.98 in. Hg to about 1.89 in. Hg. The interstage cooling reduced the volume of the flow mixture substantially, from 438 cubic feet per minute, to 212 cubic feet per minute, and the water vapor volume was reduced here from 1.60 lbs. per minute to 0.85 lbs. per minute.

The second stage liquid ring pump 14 then received the saturated vapor-gas-liquid mixture at a pressure of 3.50 in. Hg (abs) and discharged at 29.92 in. Hg. The temperature through the pump 14 rose only 6° F., from 94° to 100° F. The partial vapor pressure increased only about 0.31 in. Hg, from 1.61 in. Hg to 1.92 in. Hg. Partial air pressure rose from 1.89 in. Hg to 28.00 in. Hg, and the volume of the mixture was reduced substantially from a flow rate of 212 cubic feet per minute to 15.1 cubic feet per minute. The most significant effect obtained from the second stage liquid ring pump 14 was the condensing of the water vapor, which entered the pump 14 at a flow rate of 0.85 lb. per minute and discharged at 0.043 lb. per minute, a reduction of better than 0.81 lb. per minute.

In the example given above, the first stage compression ratio was 2.33 to 1 on total pressure, 5.8 to 1 on partial air pressure. The staging ratio for the first stage was approximately 6 to 1. Throughout the compression, the condensing effect acts like a vapor extractor, so the reduction in partial air pressure observed correlated very closely to the first stage staging ratio.

The second stage compression ratio was approximately 8.5:1, and partial air pressure was increased at a ratio of 15:1. These latter ratios illustrate the excellent performance obtained by the combination of the invention, and the full utilization of the second stage liquid ring pump's ability to handle a substantial amount of water without damage.

The example shows that the compression is obtained under nearly isothermal conditions, the temperature rise throughout the system being only about 16° F. Water vapor is condensed at a rate of about 2.20 lbs. per minute, or approximately 2,400 BTU's per minute thermal energy (56.5 h.p.). The relatively low temperature throughout compression simplified the machine design and material selection for fabricating the components of the system.

The first stage positive displacement pump 2 complements and enhances the operation of the second stage liquid ring pump 14 for vacuum systems in which a saturated vapor-gas-liquid mixture must be handled. The positive displacement pump provides exceptionally high volumetric efficiency when displacing large volumes of gas over low pressure differential. The highly efficient condensing effect during compression of the liquid ring pump enhances the volumetric efficiency of the positive displacement pump in the overall system. In addition, the liquid ring pump can operate efficiently at compression ratios up to ten to one with atmospheric discharge. When properly sized and matched, the two dissimilar pumps provide a substantially more economical and an efficient wet vacuum pumping system.

I claim:

1. A multistage evacuating pumping system, comprising in combination a first stage pump and a second stage pump each having an inlet and outlet, said first stage pump comprising a positive displacement pump and said second stage pump comprising a liquid ring pump, means providing direct fluid communication from the outlet of the first stage pump to the inlet of the second stage pump, recirculation conduit means connecting the outlet of the first stage pump to the inlet of the first stage pump and valve means operatively associated with said recirculation conduit and responsive to the pressure difference between said first stage pump outlet and said first stage pump inlet for maintaining the pressure across said first stage pump below a predetermined value.

2. The vacuum pumping system of claim 1, including auxiliary cooling means for further reducing the temperature of

the vapor-gas-liquid mixture being pumped through the system.

3. The vacuum pumping system of claim 1, including interstage cooling means disposed between the first stage, positive displacement pump and the second stage, liquid ring pump to provide additional cooling liquid mixture upstream from the inlet to the second stage liquid ring pump.

4. The vacuum pumping system of claim 1, including a separator tank for receiving the discharged condensed vapor-gas-liquid mixture from the outlet of the second stage liquid ring pump, and a gas vent disposed in the upper portion of said separator tank for discharging gases from the system.

5. The apparatus of claim 1, including a second stage liquid recirculation loop interconnecting the outlet of the second stage liquid ring pump with the inlet thereof to provide sufficient liquid to the second stage liquid ring pump for uninterrupted operation of the vacuum pumping system.

6. The apparatus of claim 5, including heat exchanger means disposed in said liquid recirculation loop for regulating the temperature of the liquid recirculated to the second stage liquid ring pump.

7. The apparatus of claim 1, in which the auxiliary cooling means includes a liquid spray injected into the fluid stream downstream from the positive displacement pump and upstream from the liquid ring pump.

8. The apparatus of claim 1, including a separator tank disposed in communication with the outlet of the liquid ring pump said tank providing means for separating gases from liquids discharged from the liquid ring pump.

9. The apparatus of claim 1, including an auxiliary bypass conduit mean connected to the outlet of the positive displacement pump and pressure-responsive valve means in said conduit to provide an auxiliary flow path bypassing said liquid ring pump at times when the quantity of fluid pumped through the positive displacement pump exceeds the capacity of the liquid ring pump.

10. The apparatus set forth in claim 1 and including a first stage liquid recirculation loop connected to the second stage liquid recirculation loop and to the inlet of the first stage pump, said first and second stage liquid recirculation loops including valve means for controlling flow therethrough, whereby the quantity of recirculated cooling liquid mixture is regulated to maintain optimum thermodynamic conditions in a vacuum pumping system.

11. A multistage evacuating pumping system for pumping a saturated vapor-gas-liquid mixture comprising a combination, a first stage, positive displacement pump having an inlet and outlet, a second stage liquid ring pump having an inlet and outlet, and means providing direct fluid communication from the outlet of the first stage, positive displacement pump to the inlet of the second stage liquid ring pump, a second stage liquid recirculation loop interconnecting the outlet of the second stage liquid ring pump with the inlet thereof to provide sufficient liquid to the second stage liquid ring pump for uninterrupted operation of the vacuum pumping system, the first stage recirculation conduit for the first stage for recirculating the saturated vapor-gas mixture from the outlet of the first stage pump to the inlet of the first stage positive displacement pump, and a first stage liquid recirculation loop connected to the second stage liquid recirculation loop and to the inlet to the first stage pump, said first and second stage liquid recirculation loops including valve means for controlling flow therethrough, whereby the quantity of recirculated cooling liquid mixture is regulated to maintain the optimum thermodynamic conditions in the vacuum pumping system.

12. The apparatus of claim 11, including a bypass discharge conduit means interconnecting the first stage recirculating conduit to a discharge outlet bypassing the second stage liquid ring pump to provide an auxiliary discharge outlet for said first stage positive displacement during startup of the system and periods of operation when the capacity of the second stage liquid ring pump is temporarily exceeded.

13. The apparatus of claim 12, including valve means in the bypass discharge conduit for regulating the discharge therethrough.

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