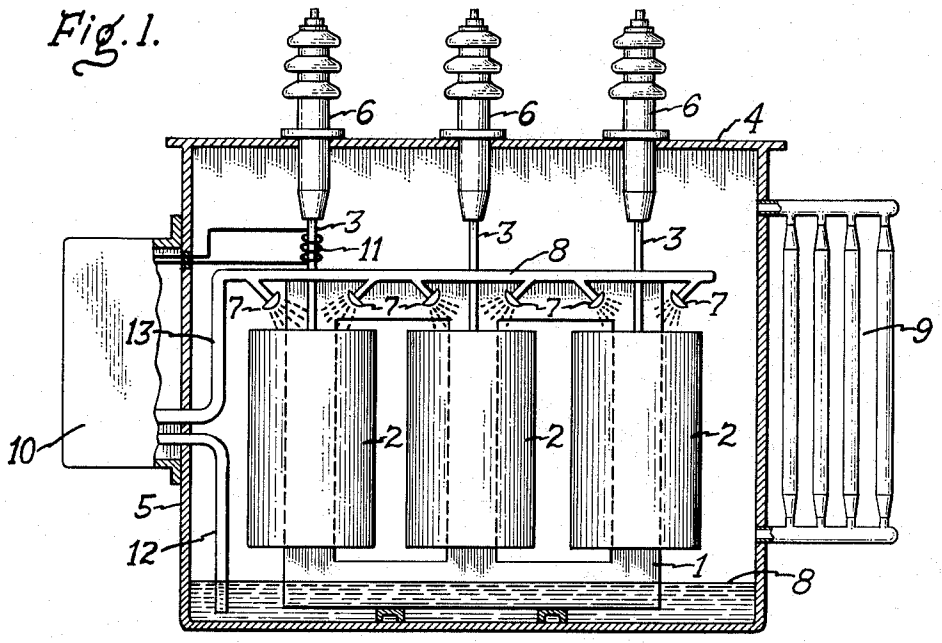
July 19, 1966 B. F. ALLEN 3,261,905

STATIONARY INDUCTION APPARATUS COOLING SYSTEM

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Fig. 1.



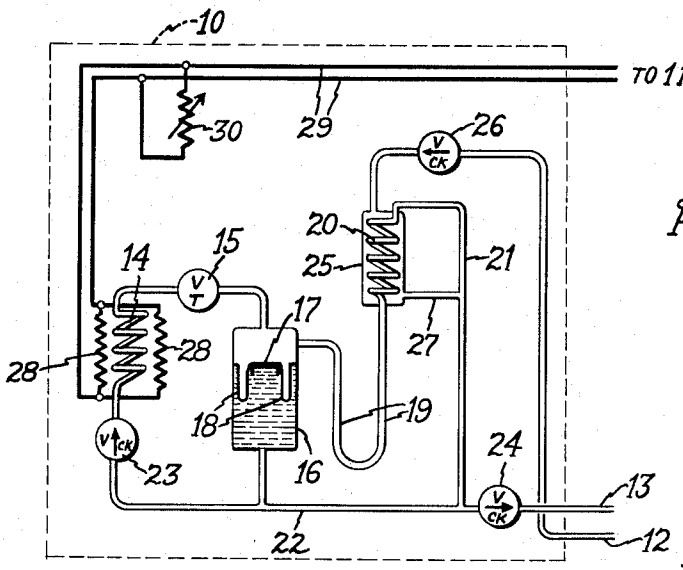


Fig. 2.

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Fig. 3.

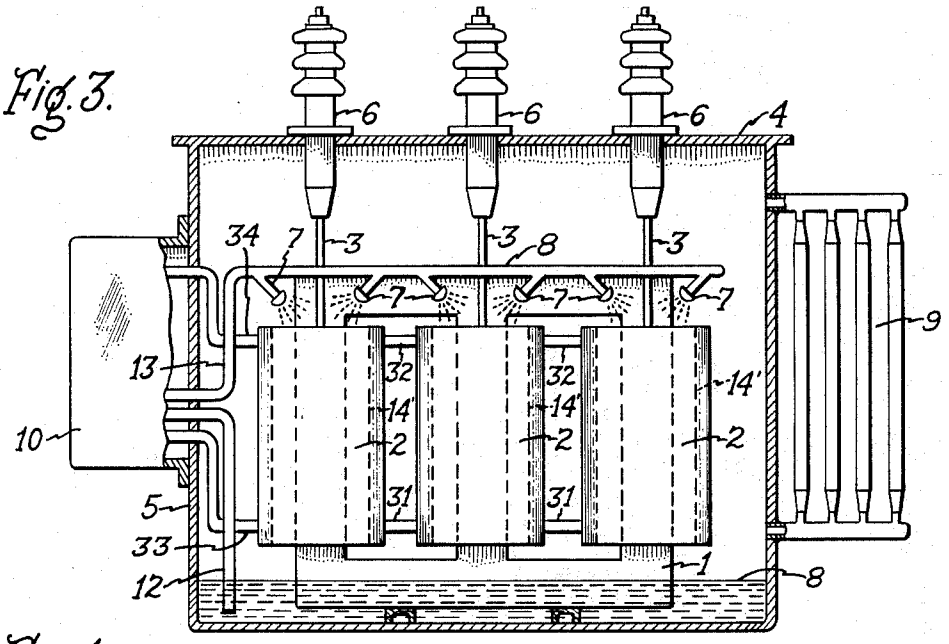


Fig. 4.

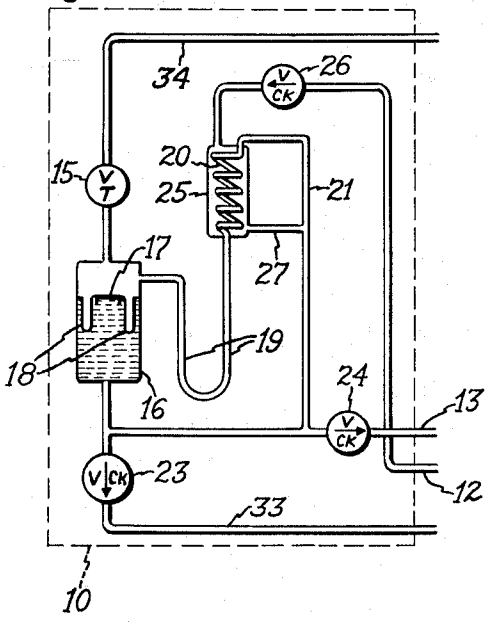
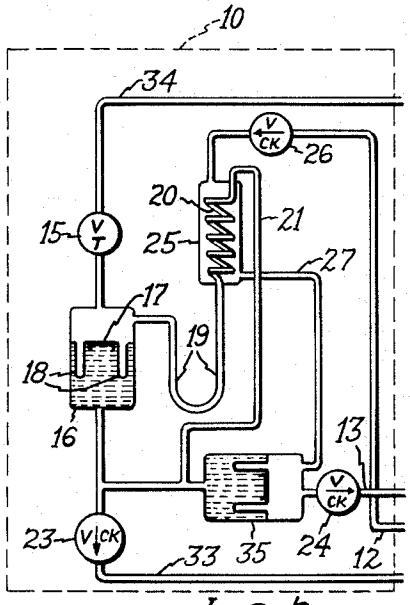


Fig. 5.



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3,261,905

STATIONARY INDUCTION APPARATUS COOLING SYSTEM

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Filed Dec. 18, 1963, Ser. No. 331,592
8 Claims. (Cl. 174—15)

This invention relates to stationary induction apparatus cooling systems and more particularly to an improved circulating fluid cooling system for stationary induction apparatus.

Stationary induction apparatus typically comprises an interlinked magnetic core and conductive coil which in operation have energy losses which appear as heat. When this heat is great enough to raise the temperature of the core and coil high enough to damage them it is conventional practice to provide a circulating fluid cooling system to hold down the temperature.

This invention is characterized by the use of a self-starting heat operated (thermally actuated) pump for circulating the cooling fluid at a rate proportional to the heat generated in the core and coil.

An object of the invention is to increase the reliability of forced circulating fluid cooling systems for transformers.

Another object of the invention is to reduce the sound or noise produced by the pumping means for forced circulating cooling systems for transformers.

An additional object of the invention is to increase the efficiency of forced circulation cooling systems for stationary induction apparatus.

A further object of the invention is to provide a new and improved cooling system for stationary induction apparatus.

The invention will be better understood from the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

In the drawings,

FIG. 1 is a partly sectionalized elevation view of a transformer embodying the invention,

FIG. 2 is a detailed diagrammatic view of a heat actuated pump for the apparatus shown in FIG. 1,

FIG. 3 is a view similar to FIG. 1 of a modification of the invention,

FIG. 4 is a view similar to FIG. 2 of a modified pump for use in FIG. 3, and

FIG. 5 is a view similar to FIGS. 2 and 4 of a two fluid pump.

Referring now to the drawings, and more particularly to FIG. 1 there is shown therein stationary induction apparatus in the form of a three-phase transformer having a three-legged magnetic core **1** on each of whose three legs is mounted a coil **2** which typically will comprise the primary and secondary or high voltage and low voltage windings and their associated insulation and cooling fluid ducts for each of the three phases. Each coil **2** has at least one lead **3** which is brought out through the top **4** of an enclosing tank **5** by means of an insulating bushing **6**. The transformer is illustrated by way of example as being of the so-called sealed dry type in that the housing or tank **5** is hermetically sealed and the core and coil assembly is not submerged in an insulating and cooling liquid.

The cooling system for the core and coil assembly is illustrated by way of example as a so-called vaporization cooling system in which liquid having a boiling point below the normal operating temperature of the core and coil assembly at the pressure within the tank **5** is sprayed on the core and coil assembly from nozzles **7** connected to a common manifold **8**. Thus when the liquid strikes

the hot core and coil assembly a comparatively large amount of heat per unit weight of the liquid is extracted isothermally from the core and coil assembly by the heat of vaporization of the liquid which is much greater than its specific heat. The vaporized liquid then condenses out on the comparatively cool surfaces of the tank **5** and is collected in the form of liquid in a sump **8** at the bottom of the tank. If necessary or desirable, the effective condensing surface area of the tank may be increased by a tubular or other shaped heat exchanger or radiator **9** connected to the tank at any suitable location.

Examples of suitable vaporizing liquids are perfluorocarbons, perfluorocarbon ethers, and perfluorocarbon tertiary amines boiling between 50° C. and 225° C., but the invention, of course, is not limited to the use of any particular fluid compositions.

While the vapors of suitable liquids have adequate and in many cases better than adequate electrical insulating properties those vapors will, of course, not be present if the apparatus is started cold, i.e. at a temperature at which substantially all of the fluid is in the liquid phase. In order to provide adequate fluid dielectric strength during cold starts it will, therefore, sometimes be desirable to insert a small amount of dielectric fluid which is gaseous at the lowest ambient temperature in which the apparatus will be operated. Suitable materials for this purpose are for example, sulphur hexafluoride (SF_6), or octafluorocyclobutane (c-C_4F_8) or C_3F_8.

For circulating the vaporizable cooling liquid, there is provided a heat operated pump in a compartment **10** attached to the tank **5**. The heat for operating the pump is supplied by current from a current transformer **11** in one of the leads **3** so that it will be proportional to the transformer current and therefore proportional to the heat generated in the core and coil assembly. The pump is shown provided with an inlet pipe **12** extending into the liquid at the sump **8** and an outlet pipe **13** connected to the manifold **8**.

The details of a suitable heat operated pump are shown in FIG. 2 wherein the coiled pipe **14** is a vapor generator whose outlet is connected through a regulating valve **15** to a vapor collecting chamber **16** having a float separator plate or diaphragm or bellows **17** and shown by way of example as connected to the walls of the chamber **16** by a flexible membrane **18**. The top of the chamber **16** is connected to a vertical U-tube **19** which in turn is connected to the inlet of a coiled vapor tube condenser **20**, the outlet of which is connected by a return pipe **21** to a pipe **22** and back to the vapor generator **14** through a check valve **23** which prevents reverse flow. The pipe **22** is also connected to the outlet pipe **13** of the pump through a check valve **24** which prevents reverse flow in the outlet pipe. The condenser tube **20** is surrounded by a condenser chamber **25** connected at its upper end to the inlet pipe **12** of the pump through a check valve **26** which prevents reverse flow in the inlet pipe **12**. The outlet of the chamber **25** is connected by a pipe **27** to the pipe **21**.

Heat is supplied to the vapor generator **14** by resistance heaters **28** energized by the current transformer **11** through conductors **29**. The effective ratio of the current transformer or the amount of current supplied to the resistance heaters **28** may be controlled in any suitable manner such as by a rheostat **30** connected in shunt across the conductors **29** so as to bleed off more or less of the output current of the current transformer **11** from the resistance heaters **28**.

The operation of the pump shown in FIG. 2 is as follows: Starting with the device cold and at rest all of the pipes and parts will be filled with the vaporizable cooling liquid and the float **17** will be near the top of

the chamber 16. However, when current flows in the coils 2 tending to heat them, current will also flow in the resistance heaters 28 thereby generating vapor in the coil 14 which passes through the control valve 15 into the collecting chamber 16 above the float 17 thus building up pressure which forces the liquid level down in the left-hand leg of the U-tube 19 and up in the right-hand leg of the U-tube and also forces the liquid level down in the chamber 16 so that as the levels in the chamber 16 and in the left-hand leg of the U-tube 19 both go down they stay at substantially the same level as they do down. This forces liquid out of the pump through the check valve 24 to the outlet pipe 13 as the liquid cannot return to the vapor generator coil 14 because the vapor back pressure therein keeps the check valve 23 closed. However, as soon as the vapor pressure builds up to a point where the liquid level in the chamber 16 and the float 17 are near the bottom of the chamber 16 the vapor will pass around the bottom of the U-tube 19 and up into the condenser coil 20 which being surrounded by comparatively cool liquid in the chamber 25 will cause the vapor to condense. This generates a partial vacuum in the pump which closes the outgoing check valve 24 and opens the inlet check valve 26 in the inlet pipe 12 through which new liquid is drawn relieving the partial vacuum. The liquid levels in the vapor collector 16 and the U-tube 19 and in the generator tube 14 then rise to their starting points and the generation of a new bubble of vapor starts causing the pumping cycle to repeat. The pump thus produces repeated impulses of liquid flow.

Inasmuch as the heat which is supplied for operating the pump is derived from the current which heats the core and coil assembly, it will be seen that the average rate of cooling fluid flow is proportional to the heat generated in the core and coil assembly. However, the ratio may be adjusted in any suitable manner such as by manipulating the rheostat 30. The pump illustrated in FIG. 2 is extremely quiet and reliable in operation as it has no high speed rotating parts for producing vibration and noise and requires no lubrication. Check valves are notoriously reliable, quiet operating devices and the float 17 membrane 18 assembly is also extremely simple, reliable and quiet in operation.

In the modification shown in FIGS. 3 and 4 the auxiliary electric circuit for supplying heat to the pump has been eliminated and the vapor generator 14 has been incorporated in the coil 2 structure such as by embedding the coil 14 in the insulation of the coils 2 which may be of any suitable type such as cellulose material or cast resinous material or the vapor generator may be in the form of a jacket surrounding each coil 2. The vapor generators 14' for each of the coils 2 may be connected hydraulically in parallel by means of pipes 31 and 32, the former being connected by a pipe 33 to the check valve 23 connected to the top of the condenser coil 20 and the latter being connected by a pipe 34 to the choke valve 15 at the top of the vapor collector chamber 16.

The operation of the FIGS. 3–4 modification is similar to the operation of the FIGS. 1–2 system in that vapor pressure produced in the vapor generators 14' embedded in the coils 2 will cause the pump of FIG. 4 to operate in the same cyclic manner as the FIG. 2 pump where vapor pressure is produced in the vapor generator 14 which is surrounded by the resistance heaters 28.

An advantage of directly using the heat generated in the coils 2 for operating the pump is that in this manner heat is not only extracted from the coils by the vaporization of the pumped liquid but also by the vaporization of the pumping liquid in the vapor generators. This is not true in FIGS. 1–2 where in fact the heat required to vaporize the liquid in the vapor generator in effect represents increased losses for the transformer as a whole. Thus in FIGS. 3–4 there is a double cooling action of the coils 2 by the vaporization of the fluid in the generators 14' embedded in the coils 2 and on the outer surface of the coils 2.

Another advantage of the embodiment shown in FIGS. 3–4 is that by reason of the parallel hydraulic connections between the vapor generators 14' associated with the three coils 2 they tend to have their temperatures equalized by thermosiphon circulation so that if for example one phase of the transformer is more heavily loaded than the other phases, the heat storage capacity of the other phases can be used to hold down the temperature of the more heavily loaded phase.

It is to be noted that both the systems of FIGS. 1–2 and FIGS. 3–4 are self-starting initially and after each shut down. Furthermore, they pump fluid for cooling purposes independently of the vaporization phenomena at the winding surfaces and do not require that an excess of fluid be delivered to the coil surfaces continuously so that the vapor pressure generated will be proportional to losses which are a function of load. In addition, in both systems fluid is pumped as long as there is fluid in the sump without regard to whether the transformer has lost pressure due to a tank leak.

The pump shown in FIG. 5 differs from the pump shown in FIGS. 2 and 4 primarily in that it is a binary or two fluid pump, i.e. the pumping fluid and the pumped fluid are not the same. This is accomplished by means of a second diaphragm chamber 35 for separating the pumping fluid on the left side of its diaphragm from the pumped fluid on the right side of its diaphragm. Also, there is no connection between the pipes 21 and 27 as in FIG. 4, pipe 21 leading from the upper end of the condenser coil 20 to the junction between the bottom of the vapor chamber 16, the check valve 23, and the left side of the diaphragm chamber 35, while pipe 27 leads directly from the bottom of the condenser chamber 25 to the right-hand side of the diaphragm chamber 35.

The operation of FIG. 5 is as follows:

So far as the pumped fluid in the pipe 12, check valve 26, chamber 25, pipe 27, right-hand side of the diaphragm chamber 35, check valve 24 and pipe 13 is concerned, the operation is the same as any conventional diaphragm type pump in that when the diaphragm of the chamber 35 moves to the left, pumped fluid is drawn up from the sump 8 through the pipe 12, the check valve 26, the condenser chamber 25, and the pipe 27 and into the right-hand portion of the chamber 35. When the diaphragm of the chamber 35 moves to the right, fluid is expelled through the check valve 24 and discharged through the pipe 13. Reverse flow will always be prevented by the check valves 24 and 26.

The operation of FIG. 5 insofar as the pumping fluid is concerned is generally the same as in FIGS. 2 and 4 in that vapor pressure created in the vapor generators 14' of FIG. 3 pushes the diaphragm 17 of the chamber 16 downward thus expelling fluid from the lower part of chamber 16 and starting the cycle of operation in which a bubble of vapor passes around the bottom of the U-tube 19 and is condensed in the condenser 20 causing a temporary partial vacuum which returns the diaphragm 17 to its uppermost position. The only difference is that the fluid below the diaphragm 17 instead of being discharged into the outlet pipe 13 through the check valve 24 is merely discharged into the left-hand part of the diaphragm chamber 35 so that the impulses of the pumping fluid provide the motivating force for reciprocating the diaphragm in the chamber 35.

By separating the pumped and pumping fluids, each may be selected for its most desirable properties for the separate functions which each performs, whereas in the single fluid pump it is necessary to compromise as to the most desirable properties. Thus the pumping fluid should have a boiling point which is slightly higher than that of the pumped fluid throughout the pressure range that the transformer will operate. This will insure complete and rapid condensation of the pumping fluid vapor

in the condenser **20** and insure continuous operation without boiling dry. Also the pumping fluid should have a heat of vaporization per unit of vapor volume at the system operating pressure which is as low as possible so as to minimize the external energy input required for pumping. Also the vapor pressure of the pumping fluid should be less than that of the pumped fluid over the range of ambient temperatures in which the transformer is designed to operate. This is desirable to insure that during a shut down period the vapor collector **16** will remain filled and the diaphragm in the chamber **35** will remain in the left-hand position ready for resumption of operation. This condition could, of course, also be maintained by a biasing spring in the diaphragm chamber if the desired vapor pressure relationship could not be attained.

Examples of suitable pumped fluids are the fluorocarbon or fluorochemical liquid consisting of a mixture of different isomers of $C_8F_{16}O$ boiling in the range of 50°–120° C. and known to the trade as Minnesota Mining and Manufacturing Company's FC–76 or $CCl_3CF_2CF_3$ (which may also be written $C_3Cl_3F_5$) known to the trade as E. I. du Pont de Nemours & Company's Freon 215. Suitable pumping fluids which provide most of the differences mentioned in the preceding paragraph are the fluorocarbon or fluorochemical liquid $C_8F_{16}O$ boiling in the range of 99°–107° C. and known to the trade as Minnesota Mining and Manufacturing Company's FC–75, or $CCl_3CF_2CF_2Cl$ (which may also be written $C_3Cl_4F_4$) known to the trade as E. I. du Pont de Nemours & Company's Freon 214.

While the binary fluid pump shown in FIG. 5 is adapted for operation with a vapor generator embedded in the windings **2** as is the case with the pump of FIG. 4, it will, of course, be obvious that the vapor generator **14** and electrical heating elements thereof of FIG. 2 could equally well be used in a fluid pump as shown in FIG. 5.

While there have been shown and described particular embodiments of the invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention, and therefore it is intended by the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a circulating fluid cooling system for said core and coil, a self-starting fluid pump including a vapor generator and operable in response to input of heat energy for circulating said fluid, and means for supplying heat to said vapor generator in proportion to the heat generated by said core and coil.

2. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a circulating fluid cooling system for said core and coil, a self-starting fluid pump including a vapor generator and operable in response to input of heat energy for circulating said fluid, and means for applying directly to said vapor generator the heat generated by said core and coil for operating said pump.

3. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a circulating fluid cooling system for said core and coil, a self-starting fluid pump including a vapor generator and operable in response to input of heat energy for circulating said fluid, and means for supplying heat to said vapor generator in proportion to current in said coil.

4. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a circulating fluid vaporization cooling system for said core and coil, a binary fluid thermally actuated pump having a pumping fluid and a different pumped fluid for circulating said cooling system fluid as the pumped fluid, and means for supplying heat to said pumping fluid in proportion to the heat generated by said core and coil.

5. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a circulating fluid vaporization cooling system for said core and coil, a binary fluid thermally actuated pump having a pumping fluid and a different pumped fluid for circulating said cooling system fluid as the pumped fluid, and means for directly using the heat generated by said core and coil for heating said pumping fluid.

6. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a circulating fluid vaporization cooling system for said core and coil, a binary fluid thermally actuated pump having a pumping fluid and a different pumped fluid for circulating said cooling system fluid as the pumped fluid, and means for supplying heat to said pumping fluid in proportion to current in said coil.

7. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a circulating fluid cooling system for said core and coil, a heat operated self-starting fluid circulating pump for said cooling system having a pumping fluid and a pumped fluid, and separate means for transferring heat from said core and coil to both of said fluids.

8. Stationary induction apparatus comprising, in combination, a heat generating core and coil to be cooled, a liquid vaporization cooling system for said core and coil, a heat operated self-starting pump for said system having a pumping liquid circuit and a pumped liquid circuit, means for extracting heat from said core and coil by vaporizing liquid in said pumping liquid circuit, and separate means for extracting heat from said core and coil by vaporizing liquid in said pumped liquid circuit.

References Cited by the Examiner

UNITED STATES PATENTS

2,640,101	5/1953	Hughes	336—55
2,682,173	6/1954	Camilli	174—15
2,761,101	8/1956	Camilli et al.	336—60 X
2,917,701	12/1959	Salton	336—57 X

References Cited by the Applicant

UNITED STATES PATENTS

2,553,817	5/1951	Af Kleen.
2,744,470	5/1956	Coleman.
2,755,792	7/1956	Van Hook.
2,757,618	8/1956	Af Kleen.
2,825,034	2/1958	Birchard.

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