Heat Exchangers with Heat Pipes for Power Transformers Cooling Improvement

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Abstract - **This paper present a new equipment in order to improve the heating transfer in medium and high power transformers. The principle of cooling with heat pipes in the cooling circuit of medium and high power transformers can be successfully applied. The transformers are provided with the classical cooling batteries has some disadvantages: large overall dimensions, reduced reliability and maintenance, increased costs, efficiency and technical performances under the level of the cooling systems with heat pipes. Keeping an eye on the disadvantages of the cooling batteries with brass tubes and aluminium or honeycomb flanges, it is advisable the use of a much more efficient new cooling system having the possibility to recover the heat energy. The changing of the classical cooling batteries of 150 kW from the medium and high power transformers with cooling batteries with heat pipes was experimented on a model with thermal dissipated power of 25 kW. The use of heat pipes to cool the oil from the medium and high power transformers has a series of important advantages: the improvement of the oil cooling process, good heat transfer, with possibilities to recover the energy, medium and high power transformer's clearance diagram dimensions' reduction.**

Index Terms - **transformers, medium and high power, cooling, heat transfer, heat pipes**

I. INTRODUCTION

The increasing of reliability of service for mean and high power transformers represents an important objective in enhancing the performances of electrical equipment intended to energy branch.

The mean and high power transformers achieved in Romania are fitted with two types of classical cooling batteries that is: a cooling battery having the tubulature made of brass and aluminium plates as paddles and the other cooling battery in a brazed design, aluminium and aluminium alloy honey comb type.

Starting from a series of disadvantages the classical cooling systems have, namely big overall dimensions of coolers, low reliability and maintainability, lack of liability, high costs etc., it was proposed the replacing of these ones with cooling batteries with heat pipes improving the oil cooling process, which have the possibility to recover the energy that, in classical version, is dissipated in air.

II. NEW COOLING SOLUTION WITH HEAT PIPES

The new cooling system, much more performing, with possibilities of recuperation of thermal energy, uses for transformers cooling, batteries with heat pipes [1]. These ones are inserted in the cooling circuit, according to the following fundamental circuit (Fig. 1).

The cooling batteries with heat pipes are carried out in two constructive versions that is:

- cooling batteries with steel tubes provided with aluminium paddles;
- cooling batteries with aluminium tubes provided with aluminium paddles.

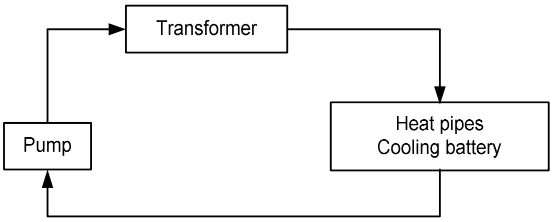

Fig. 1 The new cooling system

From the view point of the heat quantity transferred by heat pipes, the theoretical difference between these versions is only 1 - 2 % that one with aluminium being better, but the experimental results obtained on tubes identical as concerns the dimensions (one of these was made of drawn pipe of steel, the other one of aluminium) have shown, paradoxically, a very high superiority for steel. It can be concluded that, the material of witch the tube is made is not restricted by considerations regarding thermal conductivity, such as it happens for the classical heat - exchanger. The geometry of heat pipe, as essential element of cooling battery, is presented in Fig. 2.

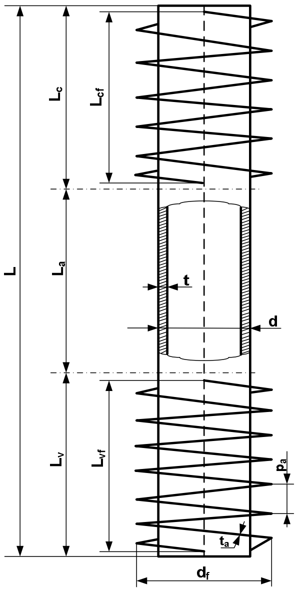

Fig. 2 The Heat Pipe Geometry

The letters significance are:

d - outer diameter of container
t - thickness of container wall
p_a- paddle spacing
t_a- paddle thickness
L_v- evaporator length
L_a- adiabatic part length
L_c- condenser length
L - heat pipe length

The heat pipe achieves the transfer of a big amount of heat, at a constant temperature, on a relatively long distance between the source fluid (hot) and the destination fluid (cold) even under the influence of a small difference between the temperatures of the two fluids, without involving the consumption of an additional amount of energy. In order to obtain a thermal transfer as good as possible, the choice of the work fluid adequate to an imposed temperature range, the compatibility of the work fluid with the container material, and also the setting up of an optimum amount of fluid are necessary.

An important advantage of the heat exchangers with hest pipes is that they assure a much better sealing during the entire operation. Thus, the thermal tubes can be well sealed in the tubular plate and between the two fluids (the gases and the air) there is a double wall (the wall of thermal tube from the vaporization zone and that from the condensation zone). In the case of corrosion of a thermal tube in the vaporization zone (on the side of hot gases) the working fluid leaves the thermal tube, stopping it from the operation, but the wall from the condensation zone remaining intact, the current of hot gases remains separated from that of air.

If some thermal tubes corrode or erode during the operation, they can be individually demounted and replaced very rapidly, shortening, this way, the stopping time of steam boiler and cheapening the repair of heat exchanger. However, the classical blast-heating apparatus cannot be generally repaired and brought back to the same working parameters as the new ones.

Another important advantage of heat exchangers with thermal tubes is that they can be very easy cleaned by using some brushes mounted inside a tube having the diameter larger than the diameter of thermal tubes and the absorption of the dust from the thermal tubes, this operation being done without demounting the thermal tubes, and in the case when the flue is not significantly disturbed, even during the boiler operation.

At these advantages it is possible to add the fact that in the case of these heat exchanges it substantially diminishes the corrosion of materials by rising the temperature of solid surfaces with which the hot gases are in contact. As above demonstrated, in the case of classical heat exchangers, the coefficient of convection on the side of hot gases is lower than that on the side of air, thus the temperature of separating wall will be closer to that of the air, namely colder. Unlike this one, the working temperature of thermal tubes is very close to the arithmetic average of the temperature of heat transfer agents. Thus, it is possible to carry out a more accentuated recuperation of residual heat, without reaching the dew point temperature.

The cooling battery with heat pipes, in module design, is achieved as an assembly of modules, the number of which is depending on the dissipated total power of the battery.

The cooling module is presented as an enclosed nest of tubes, bounded by a separation plate in oil box, air box respectively. The heat pipe is from physical point of view, a device operating isothermally on its entire length, in a continuous cycle of removing a great quantity of heat, at a small difference of temperature between the tube ends [3].

With a view of obtaining a maximum possible thermal transfer, it is required the choice of a working fluid corresponding to an imposed temperature range, the compatibility of the working fluid with container material (heat pipe), and not at last, the setting up of an optimum quantity of fluid [4]. The cooling module is formed by a tube beam being placed inside a case, separated by means of a separation plane in the box oil, air box respectively.

In the arrangement of heat pipes it has started from a pre-dimensioning of tubes, from reasons of heat transmission and also from reasons of resistance against the internal pressure of the working fluid [5].

For the design and the analysis of operation of blast-heating apparatus with thermal tubes it was made a calculation program based on the functional performance curves of thermal tubes experimentally obtained in conditions of interface close to those from the case of operation in the heat exchangers. It considers that the heat exchanger is constituted from many stages in which the thermal tubes, operating in diverse ranges of temperature, will use diverse working fluids, as was above mentioned. The graphic from Fig. 3 show the representation of heat flow recuperated depending on the number of rows composing the heat exchanger resulted from the calculation program. With this graphic we can find the necessary of heat pipes rows to transfer an amount of the heat.

The internal thermal resistances of thermal tubes have, generally, an enough low weight in the total thermal resistance. However, some modifications of functional performances of thermal tubes were underlined even at low thermal loads owed to the change of working fluid, therefore caused by the different thermodynamic and transport properties. Mainly, it is question of vaporization heat, viscosity of the liquid and of the vapor and the thermal conductivity of the liquid.

For the design and the analysis of operation of dissipated heat apparatus with thermal tubes it was made a calculation program based on the functional performance curves of thermal tubes experimentally obtained in conditions of interface close to those from the case of operation in the heat exchangers. It considers that the heat exchanger is constituted from many stages in which the thermal tubes, operating in diverse ranges of temperature, will use diverse working fluids, as was above mentioned. The internal thermal resistances of thermal tubes have, generally, an enough low weight in the total thermal resistance. However, some modifications of functional performances of thermal tubes were underlined even at low thermal loads owed to the change of working fluid, therefore caused by the different thermodynamic and transport properties. Mainly, it is question of vaporization heat, viscosity of the liquid and of the vapor and the thermal conductivity of the liquid.

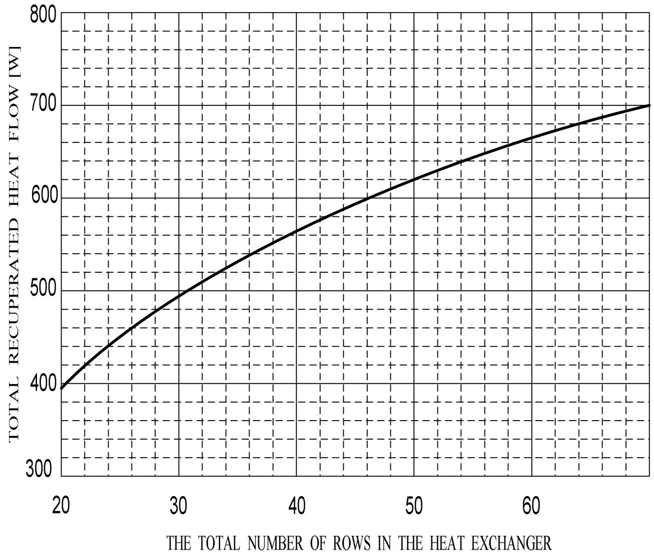

Fig. 3 The graphic representation of heat flow recuperated depending on the number of rows composing the heat exchanger resulted from the calculation program

The program comprises functions and procedures for the calculation of thermodynamic properties of the air and liquids depending on the temperature. The input data of the program are the input flows and temperatures of the air and of oil, the composition of oil, the type or the composition of the combustible, the number of thermal tubes on one row, the way of arrangement of thermal tubes in the tubular plate and the initial number of calculation beginning. It results the temperature at the output of the air / gases from each row, the working temperatures of thermal tubes, the way of the distribution on stages of thermal tubes depending on the working fluid and, possibly, its comparison with the dew-point temperature.

By the manner of achieving the tube arrangement, it is aimed at the configuration of a heat exchanger in contra flow, knowing that it is much more efficient the keeping of a temperature difference ΔT, relative constant during the process, when the working fluid changes successively the heat in contra flow in "oil phase", carrying out the evaporation and then in "air phase", carrying out the condensation. Within the experiment performed on a heat pipe, in close connection with the main geometrical parameters previously, specified, there are the following experimental variables:

- mean temperature difference	ΔT [°C]
- weight of working fluid from thermal tube	Wf [g]
- hot fluid speed (oil)	V1 [m/s]
- cold fluid speed (air)	V2 [m/s]

The mean temperature difference between the hot fluid and the cold fluid (ΔT) is one of the most important performance parameters of heat pipes.

The increase of mean temperature difference has a strong stimulate effect on the energy quantity transferred in the time unit through the surface unit of heat pipe. In order to replace the classical cooling batteries of 150 kW from mean and high power transformers with cooling batteries with heat pipes, a cooling module having aluminium tubes with dissipated power of 25 kW and overall dimensions 700 x 888 x 1034 mm was experimented. The arrangement of the tubes within this module was done on 2 lines (22 tubes on a line) the separation plate to circumscribe to condensation and vaporisation zones being arranged such as:

- evaporator length 201 mm;
- condenser length 750 mm.

These 2 lengths are in a ratio considered as being optimal, between the length of condenser, respective evaporator, the other dimensions related to the geometry of tube and tube arrangements being presented below:

- tube length L = 993 mm;
- outer diameter of container d = 16 mm;
- pipe thickness t = 1 mm;
- paddle thickness t_A = 0,3 mm;
- paddle length L_A = 836 mm;
- paddle width l_A = 48 mm.

As a work fluid for heat pipes it was used acetone.

The experiments performed together with TRANSTERM BRASOV on a module with the dissipated thermal power of 25 kW, with aluminium tubes and using acetone as working fluid for the heat pipe has shown the increasing of thermal performance, in the same time with oil speed increasing. The measurements were done on the oil side, where the necessary thermodynamic parameters could be measured and calculated with accuracy. By means of hydraulic networks used it was varied the oil flow, respectively were then into account three values of this one, for which measurements and calculations of other parameters were performed.

The experimental results are presented in Fig. 4, where the dependence between heat transfer (dissipated power) Q and mean temperature difference ΔT was set up, for few speeds of oil.

The mean temperature difference ΔT is given by the relation:

$$\Delta T = (T'_1 + T''_1) / 2 - (T'_2 + T''_2) / 2 \qquad (1)$$

where:

T'_1 = oil temperature at cooler inlet;
T''_1 = oil temperature at cooler outlet;
T'_2 = oil temperature at cooler inlet;
T''_2 = oil temperature at cooler outlet.

In Fig. 4 it is presented the variation of the dissipated heat, depending on the temperature difference for three speeds of the oil.

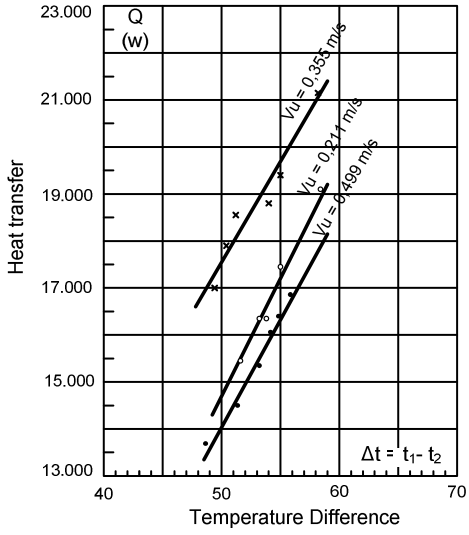

Fig. 4 Dissipated heat function the temperature difference

III. CONCLUSION

As a result of experiments there were drawn the following conclusions:

- at speed of 0,439 m/s, the spreading of the points on the diagram from Fig. 3 denote is the unsteadiness of heat pipes operation, because of the approaching to drive limit;

- it is estimated that the optimal speed of the oil is the range 0.3 - 0.4 m/s

In order to improve the functional performance of cooling module, ammoniac will be adopted as work fluid, estimating that functional performance of module will increase with, at least 35%.

The structure of pipes with paddles should be composed of steel pipes with aluminium paddles (the length of steel pipes will be 2400 mm) estimating that the functional performance will increase with about 10%.

As a conclusion, the use of heat pipes for cooling the oil from mean and high power transformer has a series of important advantages against the classical solutions used at present:

- higher heat transfer referred to volume and weight, due to the use of pipes with paddles, both on the air and the oil side;
- high reliability because every heat pipe of the packet is an independent heat exchanger. Accidental failure of a number of heat pipes does not lead to the playing out of operation of the entire cooler;
- reduced working expenses due to the use of fans with much higher powers;
- possibility of achieving a module design, so being obtained high power batteries;
- low energy consumption at the beneficiary, by decreasing the power consumed by the cooling subsidiary circuit of the transformer.

From the resulted diagrams, it is estimated that the optimum speed of the oil is between 0.3 - 0.4 m/s.

To improve the functional performances of the cooling module, acetone will be replaced by ammonia, hoping for an increase of the capacity of heat delivery by 35 %.

As a conclusion, the cooling of the mean and high power transformers with heat pipes batteries has many advantages confronted by the classical solution: a higher heat transfer capacity, high reliability and reduced energy consumption.

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