THE AIR-COOLED CONDENSING EQUIPMENT "SYSTEM HELLER" A COMPREHENSIVE SURVEY

By

T. JÁSZAY

Polytechnical University, Budapest, Department of Energetics

In highly industrialized areas the ever growing pace of production goes along with ever increasing difficulties in meeting the cooling water demand of industry and condensing power stations. Since in condensing power stations generally only a small rise in cooling water temperature is permissible, the quantity of water needed for cooling is tremendous. This fact has often caused the designers to resort to forced decisions in siting power stations when, due to the scarcity of water, the site otherwise most advantageous from the point of view of fuel and consumers, cannot be chosen. Especially serious is this situation in connection with nuclear power stations which, owing to the small costs involved in fuel transportation, are independent of the fuel basis but their cooling water demand, due to the inferior thermal efficiency being far in excess of that of conventional power stations, becomes a problem of paramount importance.

These facts have lately directed the attention toward such equipments which apply air instead of water for cooling and condensing, respectively.

The condensing equipment „System Heller"

Until now condensing power stations have adopted a method of condensing the turbine exhaust steam directly in air-cooled heat exchangers. By this method huge steam quantities have to be passed through steam pipes from the steam turbine to the outdoors heat exchangers at deep vacuum and possibly small pressure drop. Owing to the excessive specific steam volumes, these pipes were of likewise excessive dimensions and caused not only considerable difficulties in arrangement but also high investment and maintenance costs. In addition, even the smallest leakage in the pipe system or in the vast heat exchanger surface might permit ingress of air into the system and with it a deterioration of the vacuum would set in, seriously impairing the operational safety and availability of the equipment.

In the recent years the air-cooled condensing equipment known as "System Heller", invented by Dr. László Heller, professor of the Budapest Polytechnical University, has reached the stage of realization and aroused world-wide attention.

In the following a detailed description of this system will be given.

In the air-cooled condensing equipment "System Heller" the turbine exhaust steam is condensed in a jet condenser, by means of cooling water of condensate quality. Condensate and cooling water exit from the condenser together, whereafter the water is divided into two parts. One part, equivalent in quantity to the condensate, is being fed back into the boiler while the rest — recooled in an air-cooled heat exchanger first — is used once more as cooling water.

Fig. 1 illustrates the schematic arrangement of an air-cooled condensing equipment according to the Heller system. As shown, the exhaust steam flows from the turbine to the jet condenser, while condensate and cooling water collect in the condenser base whence pumps deliver part of it to the boiler and part to the water-to-air heat exchangers, the so-called "dry cooling towers". The recooled water, then, passes back to the condensers through the water turbine and is again used for condensing the steam being exhausted from the turbine. (The power generated in the water turbine supplies part of the power demand of the cooling water pump.)

By proper adjustment of the water turbine and proper dimensioning of cooling water pumps, a pressure, slightly above atmospheric, may be maintained throughout the entire cooling water system, preventing the penetration of air into the system. Leakages are immediately indicated in this way by sprays issuing at the faulty points. In smaller equipments throttle valves may be used in place of the water turbine.

The piping between condenser and heat exchangers does not exceed in its dimensions that of the conventional wet cooling towers and the system, in general, does not include any factors whatever which would set a limit to its unit capacity.

As indicated by the arrangement and its explanation, the cooling water system, after its initial priming with water of condensate purity, does not need any further water and may be operated by circulating this initial water quantity without any make-up. Circulating water of feedwater quality, even through the cooling water system, enables the application of a jet condenser which, as an advantage, is of considerably simpler construction than a surface condenser. In addition, though of smaller dimensions, a jet condenser ensures smaller final temperature difference, in other words, it enables the production of higher vacuum at identical cooling water conditions.

The application of jet condensers operated with cooling water of feedwater quality, is particularly advantageous in power stations working at supercritical pressures. In such power stations, namely, penetration of cooling water into the condensate through leakages of the heat exchanger surface might be extremely dangerous and this danger may be prevented only by the use of expensive installations (for instance the so-called "Polizeifilter"). Finally, in connection with jet condensers, neither the deterioration of vacuum due to the contamination of condenser tubes and with it the consequent drop in turbine output, nor the recurrent outages during the periodical cleaning of condenser tubes must be reckoned with.

There being no need for cooling water make-up the costs incurred by investments for cooling water and its operation, are abolished. In other words, there being no cooling water demand, power stations equipped with such condensers may be sited at the point most advantageous from other considerations, independently of cooling water supply — even in a desert.

From the point of view of arrangement, the "dry cooling towers" of the air-cooled condensers are easier to place than the conventional wet towers, owing to the fact that a dry cooling tower, though warming it up, will not humidify the air, consequently it may be built in the vicinity of any delicate equipment. It may be erected close to the buildings of the power station, close to the outdoor switch gear and it will not, even in winter, cause ice formation on railway tracks or communication roads.

Highly advantageous is the air-cooled condensing equipment "System Heller" in connection with siting and operating of nuclear power stations. This will be detailed later.

An air-cooled condensing unit of 5 t/h steam capacity, operating according to the Heller system, was built a few years ago in Hungary. This plant, during this period, has proved most satisfactory in its operation and yielded very good experimental results. On ground of its operational experiences a 13 MW capacity equipment is

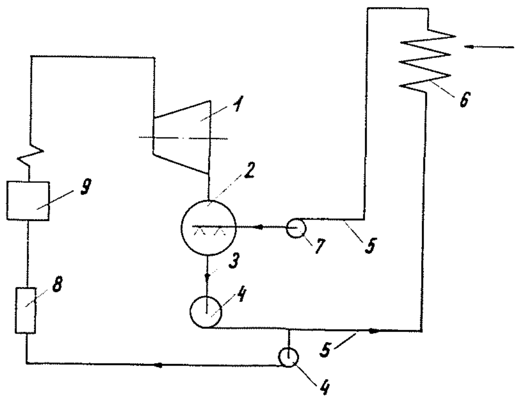


Fig. 1

1. Turbine
2. Jet condenser
3. Water pipe
4. Pumps
5. Cooling water pipes
6. Heat exchangers
7. Water turbine
8. Feedwater tank
9. Boiler

under construction for the power station of the Danube Iron Works (Dunai Vasmű) in Hungary, further one 120 MW capacity unit for England and one of 32 MW capacity for China will be supplied with "dry" cooling towers. In addition, several units of capacities ranging between 5—150 MW are in the designing stage for various foreign parties.

Experimental plant

The experimental plant had been constructed in 1954 for the condensation of 5 t/h steam. It is so dimensioned that at 15° C ambient air temperature a condenser temperature of 43° C may be ensured. With rising outside air temperature the condenser temperature naturally also rises above the 43° C value. The difference between the temperatures of cooling air and condenser can be adjusted by appropriate heat exchanger dimensions and its value is at all times determined on ground of economy calculations.

Figs. 2 and 3 show the construction of the cooling tower.

The heat exchangers are arranged in zigzag formation around the base of the cooling tower. The cooling air is sucked through the heat exchangers by means of an axial flow fan with vertical shaft. In order to reduce exit losses, a diffusor had been built above the fan. (It should be pointed out that the high-capacity condensing equipments now under construction are operated mainly with natural draught since in large plants this process proved to be more economical in most cases.) The heat exchanging surface consists of strip-finned tubes made of pure aluminium (99,5%). Its thermal characteristics will be described later in detail.

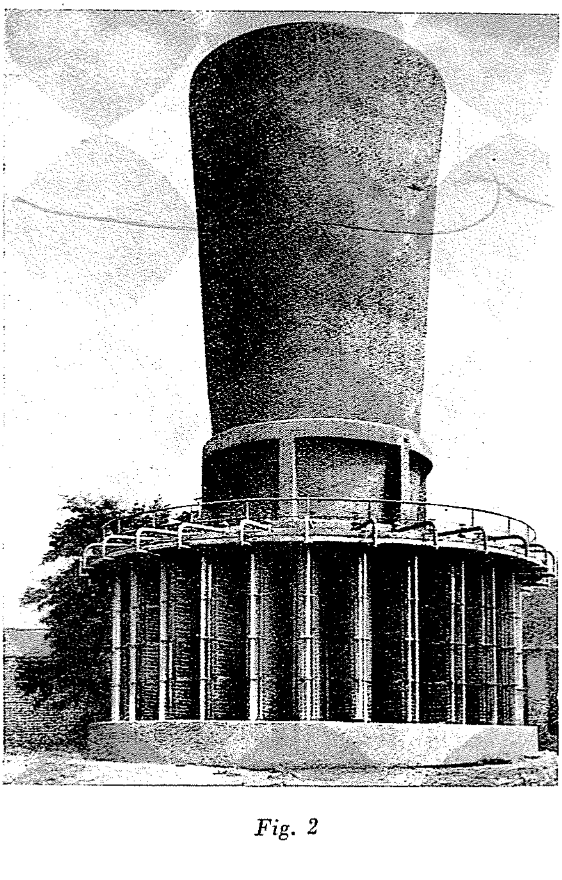
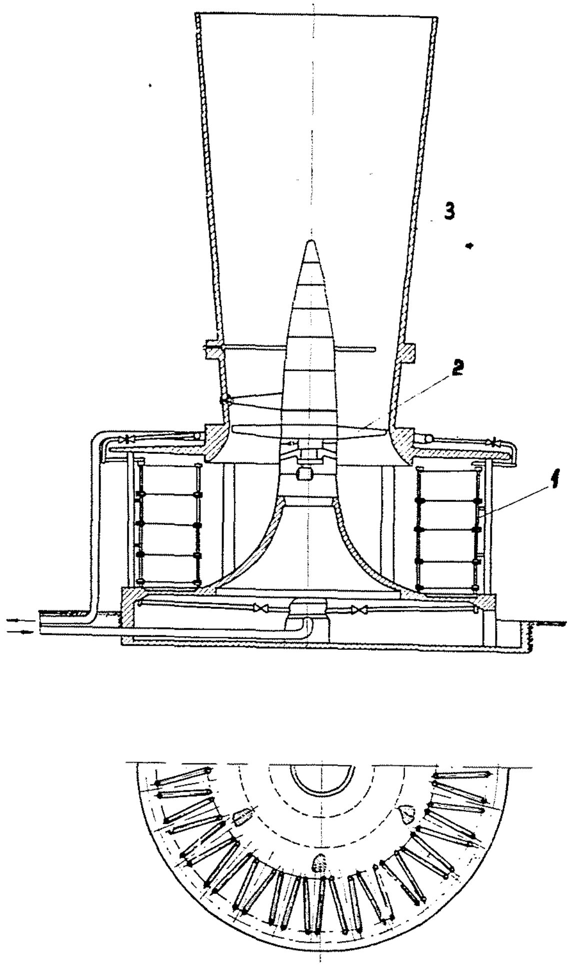


Fig. 2

In continuous operation the equipment has justified the expectations in every respect. On the part of the personnel the operation has not necessitated attention in excess of



1. Heat exchanger
2. Fan
3. Diffuser

Fig. 3

that needed in conventional steam plants, on the contrary, some duties which hitherto formed part of the routine — as for instance the cleaning of condenser tubes and the maintenance of the equipment for feedwater treatment — are rendered unnecessary. The heat exchangers manufactured of pure aluminium have proved their worth excellently: though the connecting pipework is made of steel, no traces whatsoever of corrosion could be found. Some preventive measures had, of course, been taken in order to avoid corrosion: the aluminium parts had been coated by a protective oxide layer, according to the so-called MBV process; all points where aluminium might come into contact with heavy metals, were carefully insulated electrically. Accordingly, all pipe joints and fastenings had been manufactured as individually constructed pieces.

As regards the soiling of the heat exchanger surfaces, the equipment had to stand an extremely rigorous test inasmuch as the transport roads of the attached manufacturing plant went close to the cooling tower and the dust caused by the heavy traffic was sucked by the axial-flow fan directly onto the heat exchangers. Inspite of this fact the heat exchanger elements had been in operation for a whole year without cleaning when they were washed down with water for the first time. The water jet visibly removed a great deal of dirt and dust deposited on the surfaces, still there was hardly any perceptible improvement to be experienced in the output of the heat exchangers afterwards. This clearly indicates that even in similar unfavourable conditions one annual cleaning of the surfaces is sufficient which, if necessary, may be carried out during operation.

In condensing equipments operating with a closed cooling system, the freezing danger of the heat exchangers is prevalent. The test equipment underwent a very thorough examination also in this respect.

The equipment as well as its first priming and drainage are manually operated. At the time when it had been put into operation, labour shortage permitted only five days' work weekly and even then only in two shifts. This circumstance caused considerable difficulties because on the one hand it enabled penetration of oxygen into the cooling water with each filling or drainage, and in cold weather it augmented the freezing danger, on the other. In cold weather the manipulations pertaining to the filling-up or drainage must be carried out with extreme rapidity and this necessitates the presence of skilled and well-disciplined personnel. The whole filling-up and drainage operation, even with the fan at standstill and with overheated cooling water, must be carried out within 2 minutes since, due to the little water content of the heat exchangers and to their extremely high efficiency, the water temperature falls rapidly. During this short time also the deaeration of the water pipes or their filling up with air must be carried out. In spite of the fact that the test equipment was manually operated and the task imposed on the personnel great and responsible, no harmful effect was experienced.

In continuous operation the above described difficulties did not arise at all and the equipment worked smoothly and without disturbances. However, in equipments of higher capacity manual control should be abandoned and starting and switching-off of the equipment should be effected automatically.

Strong wind or snowstorms had no influence whatever on the smooth operation of the equipment.

Present stage of development

As already stated, equipments of 5—150 MW capacity are in the designing stage or under erection. Based on the experiences gained in the experimental plant and on the vast material of data collected during the designing work and the studies, a method for economical dimensioning industrial-scale equipments, for their control, for measures to be taken in emergency (for example in freezing danger), and for laying out a heat flow scheme capable to satisfy all demands, have been developed.

Condensing equipments, generally, have to be designed to a given steam turbine characterized by the optimal vacuum and the quantity of steam or heat delivered to the condenser, at rated load. The aim of setting the economical dimensions of the air-cooled condenser, is to determine the rated ambient air temperature, and the optimal combination of the factors influencing the difference between rated air temperature and optimal condenser temperature. The difference between these temperatures depends in the first place on the construction and size of the heat exchanging surfaces, the quantity of circulated cooling water and the draught on the air-side of the heat exchangers. There exists always an optimal combination for the enumerated factors which appears most economical as a resultant of investment costs and overhead expenses.

The effect of the factors to be considered in economy calculations may be described as follows: the condenser temperature affects the turbine output at identical steam quantity and identical initial steam characteristics. The difference between condenser and outside air temperature, on the other hand — at a given heat exchanger construction — is determined by the volume of circulated cooling water, the heat exchanging surface, and the draught on the air-side of the heat exchangers.

It is obvious that the additional output yielded by the turbine and the power required by the cooling water pump for circulating the water, are items of overhead character while the size of the heat exchanging surface is definitely an investment item. If natural draught were used, the pressure drop on the air-side of the heat exchangers would be of the character of an investment item (since it depends on the tower height), the application of forced draught, again, would be an overhead item (since the power demand of the fan would change in the first place and not its cost). In consideration of all these factors and also of the conditions experienced in the course of a whole year as based on the annual temperature duration chart and on the actual costs of fuel, electric power, heat exchanger, and erection — we shall arrive at the most economical solution.

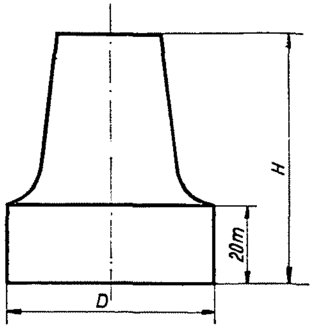
Such economy calculations have shown, for instance, that in large units it is preferable to use natural draught for driving the vast air quantities through the heat exchangers — contrary to the forced draught as had been applied in the pilot plant. However, statements of general validity cannot be made in this respect and in each individual case individual decisions are to be made as regards the ventilation system, in due consideration of all relevant factors.

To the use of natural draught cooling towers to advantage, the application of special strip-finned heat exchanger elements has greatly contributed. These elements are capable to ensure remarkably good heat transfer coefficients even at very small air-side velocities and pressure drops.

For the sake of information in Fig. 4 we furnish the outer dimensions of a natural draught cooling tower for European climatic conditions, attached to a 50, a 75, and a 100 MW capacity unit, respectively, and in Fig. 5 the sketch of a forced draught cooling tower is shown, designed for an equipment of lower output. (The overall height of a cooling tower for a 25 MW capacity turbine is approximately 30 m, its base area 25× ×25 m.)

The control of the equipment is a problem of vital importance as any divergence from the "optimal" vacuum, should it occur upwards or downwards of the optimum value, makes its harmful effect felt on the economy of power production. It is obvious, on the other hand, that if no control whatever were applied, the condenser pressure would undergo changes in the function of outside air temperature and actual load. Should, for inst., the outside air temperature exceed the rated value, the condenser temperature would inevitably also rise, nearly in proportion to the temperature rise. Should, however, the outside air temperature remain below the rated air temperature level, the falling of the condenser pressure, below the optimal value, can be prevented by appropriate measures and even a simultaneous decrease in power consumption of the auxiliaries may be achieved.

The equipment offers an extensive field for various control methods. Among others by changing the direction of water flow in the heat exchanger elements, that is, by switching over from cross-counter flow to cross-direct flow, the heat transfer conditions can be deteriorated. The circulated cooling water quantity may be reduced by the adjustment of the pump blades, and finally the cutting out of part of the heat exchanger



		N=50 MW	N=75 MW	N=100 MW
D	m	~70	~70	~80
H	m	~55	~80	~80

Fig. 4

surface by drainage is possible. In connection with natural draught towers there are further ways of control within this range, namely by letting "false" air into the cooling tower through the cut-out heat exchanger surfaces, thereby decreasing the draught of the heat exchangers still in operation.

These methods of controlling the air-side heat transfer are preceded in forced draught towers by a decrease in fan speed, or the cutting out of fans. This method also goes along with a saving in the power demand of the plant auxiliaries.

As, already stated, the above measures have to be taken in order to maintain the optimal vacuum behind the turbine even in cold weather and concurrent small loads. However, this wide range of control possibilities plays an important part also in the fight against freezing danger, ensuring the output of the heat exchanger to be maintained at a level, even in decreasing ambient air temperatures, which will prevent the freezing of the equipment.

The above-described control methods, in general, suffice to eliminate freezing hazard still, in exceptional cases, as are for instance extremely cold weather and simultaneously very small turbine load, even a completely controlled equipment may be threatened by frost. In such emergency, automatic valves inject live steam into the condenser and warm up the water arriving there from the cooling elements. Similarly, in cases of turbine failure, automatic appliances take care of the drainage of the heat exchanger elements, within one minute.

Fig. 6 illustrates the heat flow diagram meeting the tasks outlined above.

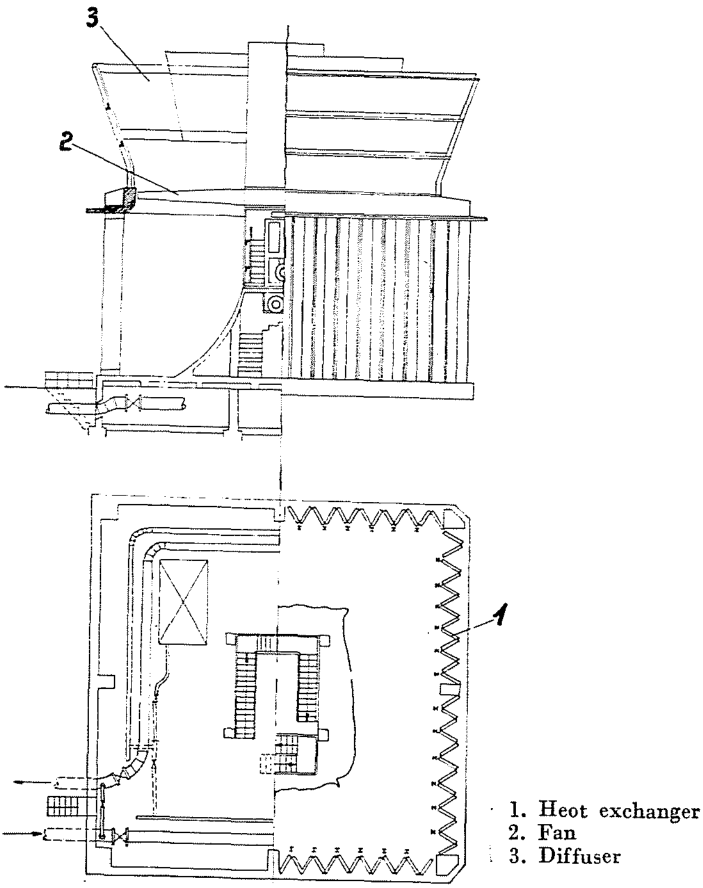


Fig. 5

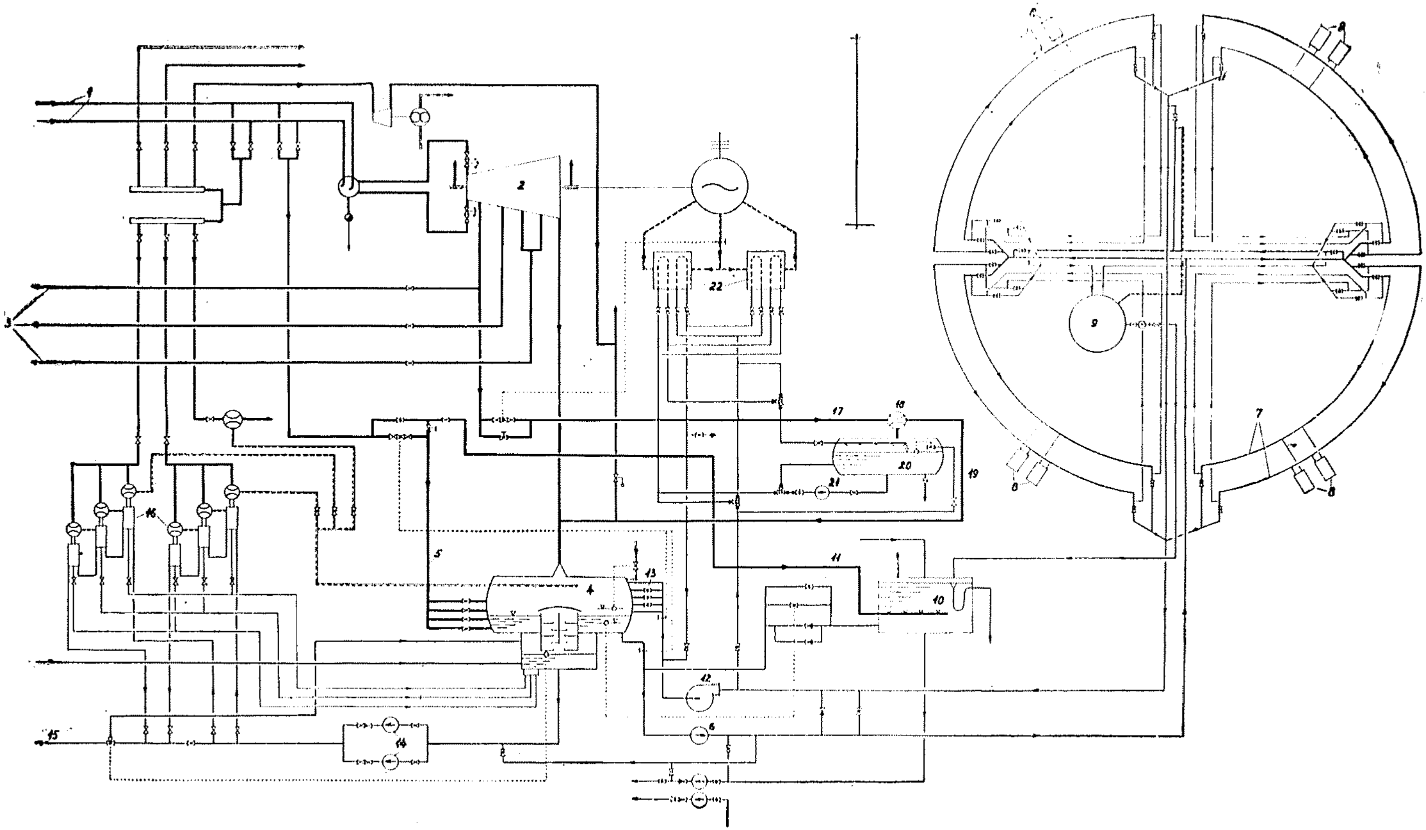


Fig. 6

1. Steam main
2. Turbine
3. Bleedings
4. Jet condenser
5. Steam pipe
6. Cooling water circulating pump
7. Cooling water distributing pipes
8. Heat exchanger elements
9. Water tank
10. Water tank
11. Steam pipe
12. Water turbine
13. Valves of jet-groups
14. Feedwater pump
15. To feedwater heaters
16. Ejectors
17. Working steam pipe to ejector
18. Ejector
19. Pressure pipe to ejector
20. Flash tank
21. Cold water circulating pump
22. Generator air cooler

(17–22: Generator cooling equipment)

To the jet condenser, located behind the turbine, the suction pipe of the condensate pump, the pipe of the cooling water pump, that for the recooled water coming from the cooling tower, further a steam pipe and the pipe for the deaerating ejectors, are joined. In order to ensure an identical head for either pumps even at varying working conditions, there are two independent water levels in the condenser, one in the condenser space proper, the other in the condensate tank built to the condenser. In this way the pumps suck from two different independent water levels. The pipe for the recooled water, leading to the condenser jets, is divided into several branches to enable the groupe-wise cutting out of jets. This ensures an adequate pressure for the jets even at small loads. The steam pipes, joined to the condenser, serve for the warming up of water in frost, to prevent failures.

The cooling water pump presses the water into the cooling columns through the distributing system, located beneath the cooling towers. Thence, after being first recooled, the water flows once more to the condenser jets. The operation of cooling water pumps and water turbine must be properly co-ordinated in order to maintain, even under widely variable conditions, the overpressure throughout the entire cooling water system, which is indispensable to prevent air ingress. For the sake of economical control, machines with adjustable blading take care of this task, whereas in small equipments instead of the water turbine, throttling valves are inserted.

The distributing pipe system beneath the cooling towers, ensures the feasibility of the control methods outlined above. These help the adaptation of the equipment to variable load and temperature conditions. The equipment is in most cases remote-controlled from the engine house. In emergency, the pipe system beneath the tower, together with the air suction valves mounted on the cooling columns, carry out prompt and automatic drainage of the equipment.

The atmospheric tanks, shown in the diagram, serve for the storage of water needed for the priming of the cooling columns or for their preheating, or else — if the system is being drained — for holding the water content of the cooling tower. One of these tanks is located in the engine house, the other below the cooling tower.

The diagram includes also an equipment for the artificial cooling of the electrical generator. This equipment, which works on the principles of patents developed at the Department of Energetics of the Budapest Polytechnical University, had been described at the occasion of the CIGRÉ (Conférence Internationale des Grands Réseaux Électriques à Haute Tension), at the 1958 Montreal session of the World Power Conference, and in one of the recent issues of the present periodical, so we shall not go into its detailed description.

The heat exchangers

The realization of the air-cooled condensing equipment "System Heller" had been greatly advanced by the special heat exchang-

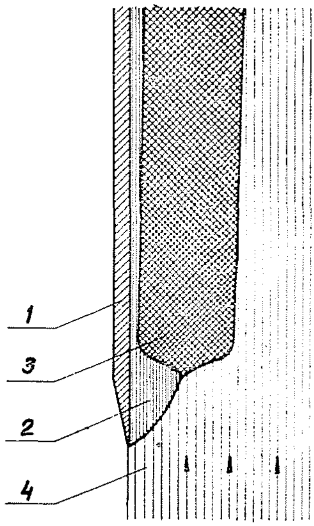


Fig. 7

ers as developed by Mr. László Forgó. The application of special heat exchangers was necessitated by the small temperature differences available for the heat transfer and by the fact that for the extraction of excessive heat quantities from the condensers of the steam turbines vast air quantities have to be moved, owing to the small specific heat of the air and its small permissible warming up.

At the same time while in forced draught cooling towers the air-side draught is limited by the volume of electrical power used for the driving of the fans, in natural draught towers it is limited by the tower height and its investment costs. To be able to build an economically working air-cooled condensing equipment, heat exchangers had to be evolved first which, at relatively small first cost, could achieve good heat transfer at small temperature differences and small air-side resistance.

The heat exchangers developed by László

Forgó consist of slotted aluminium strips threaded on thin aluminium tubes. Water flows within the tubes and atmospheric air passes outside of them. The heat exchangers, as well in construction as regarding their material, essentially differ from the conventional and generally known types.

In order to obtain small air-side resistance in the course of heat transfer even at excessive air volumes, the cooling air must have a slow flow along the heat exchanging surface. And, to achieve a good heat transfer coefficient in spite of the small flow velocities, special fins are required.

As illustrated by Fig. 7, during the flow (4) along plane surface (1), the air particles in

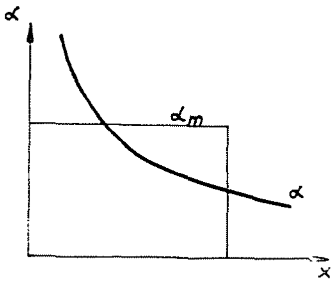


Fig. 8

close contact with the surface will be retarded by friction. Of these retarded particles a boundary layer builds up along the heat exchanger surface, consisting of a laminar (2) and a turbulent (3) part. As to be seen, this boundary layer is continuously increasing in thickness along the length of the plane surface and, in consequence thereof, the heat transfer coefficient in the direction of the flow, is continuously deteriorating (Fig. 8). This phenomenon at the same time points to the most efficient method for the amelioration of heat transfer coefficient, namely, to break up the heat transferring fins into narrow strips at right angle to the flow (Fig. 9), because this way the boundary layer cannot form and thicken as it does on plane surfaces but, on account of the serrated surface, it must build up anew after each interruption. Thus with strip-finned tubes the average thickness of the boundary layer along the surface is considerably below that on a plane surface of identical area, improving naturally the heat transfer coefficient to a great extent.

With the application of strip-finned surfaces as the one described above, a heat transfer coefficient of 80—120 kcal/m^{2}h$^\circ$C may be achieved.

The material of the strip-finned heat exchangers is one of their principal characteristics. They are, in their entirety, manufactured of pure aluminium (99,5%), a metal of very small specific weight and extraordinarily good heat conductivity. These two characteristics render aluminium eminently suitable for the manufacture of inexpensive and highly efficient finned heat exchanger surfaces. To determine the advantages of aluminium a comparison may be drawn between aluminium, copper, and unalloyed steel. As known from the literature, in economy calculations of finned heat exchangers,

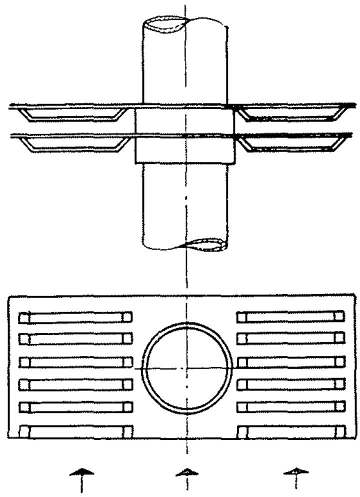


Fig. 9

the quotient ϱ/λ must be taken into consideration where ϱ represents the density of the material, and λ stands for the heat conductivity factor.

The table hereunder indicates the initial data of the comparative economy calculations and their results, based on costs in Hungary.

The material costs forming the basis of the calculations are average costs, thus consideration has been taken of the fact that the price of thin-walled tubes needed for the heat exchangers, is far in excess of the price of the material for the fins proper. The price differences vary widely and are strongly dependent also on the type of construction, consequently, the values in the fifth column might be divergent. The fourth column indicates the quantity of each metal to be used up for identical heat output and identical construction. When compiling the table, aluminium had been taken as unit value. Based on aluminium the table shows that 1,8 times more is needed of copper and 11,8 times as much of steel for the same

Table I

MATERIAL	ϱ kg/m³ 1	λ kcal/ mhC 2	ϱ/λ kg hC / m² kcal 3	ϱ/λ / ϱ/λAl 4	Price / Price/Al 5
Copper	8900	320	27,8	1,80	2,3
Aluminium 99.5 %	2700	176	15,4	1,00	1,0
Unalloyed steel	7850	43	182,0	11,80	5,9

heat output. If, in addition to the ratio of material, also the ratio of prices is taken into account and again aluminium considered as basic unit, we arrive at the figures of the fifth column. This column shows that the material costs of copper are 2,3 times and that of steel 5,9 times those of aluminium.

It has to be noted that the table gives remarkably high prices for steel. This is due to the relatively very high price of seamless, thin-walled precision-tooled steel tubes.

As seen from the foregoing, aluminium is excellently suitable for the manufacture of heat exchanger elements required for the air-cooled condensing equipments. However, some constructional problems must still be overcome. These are in the most part problems of technological nature, further those arising in connection with corrosion. Corrosion hazard had been eliminated in the following way: a technology was evolved for bonding the fins and tubes by a completely cold process, ensuring at the same time good heat conduction. Though the low creep strength of aluminium is generally known, this technology has given excellent results during the years of operation.

A similarly suitable process was developed for the bond between the tube ends and the header boxes. The solutions to the special constructional problems were such as abolished the major part of the corrosion problems namely almost all parts of the heat exchangers were manufactured from the same material, of aluminium of 99,5% purity, which fact by itself precludes the tendency for corrosion.

Due care has been taken also of the contact points between heat exchanger surfaces and pipe system or the stiffening framework. These being of heavy metals, electrical insulation has been provided to prevent corrosion.

As already mentioned in the chapter dealing with the operation experiences of the experimental plant, all these measures proved to be fully satisfactory.

To compare the output of heat exchanger elements with smooth and with finned ribs, respectively, the results yielded by a series of comparative measurements are shown in Fig. 10. The abscissa shows the specific

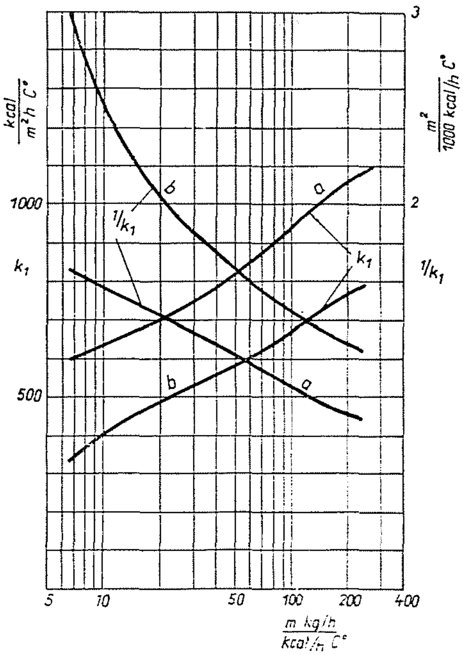


Fig. 10

fan output while on the ordinate the k heat transmission factors, respectively their reciprocals are indicated, the values being referred to 1 m² frontal area of the heat exchanger surface. The heat transfer factor determined is by the equation:

$$Q_1 = k_1 \Delta t$$

where Q_1 represents the heat quantity yielded by 1 m² frontal area of heat exchanger surface and Δt the temperature difference between heating steam and air inlet. The curves show the results for finned (*a*) and smooth (*b*) heat exchangers. As seen from the chart in the wide range of specific fan output (N_1) the heat output of strip-finned heat exchangers exceeds that of the smooth ones. The value of $1/k$ is proportionate to the space requirement of the heat exchanger and also to its bulk. It is obvious from the chart that the strip-finned equipment, with its lower demand both in fan output and in space, is more advantageous even in this respect. The heat exchanger elements, to be used in industrial-scale equipments, may be assembled from units as illustrated in Fig. 11. According to needs, two, three or four such elements can be assembled vertically.

It should be mentioned here that the Forgó-elements may be used also in various other fields, as for instance in solving condensing problems encountered in technological processes, or special cooling problems of the chemical industry. They have been successfully applied in closed-circuit coolers of electric generators and in the cooling of radio transmitters.

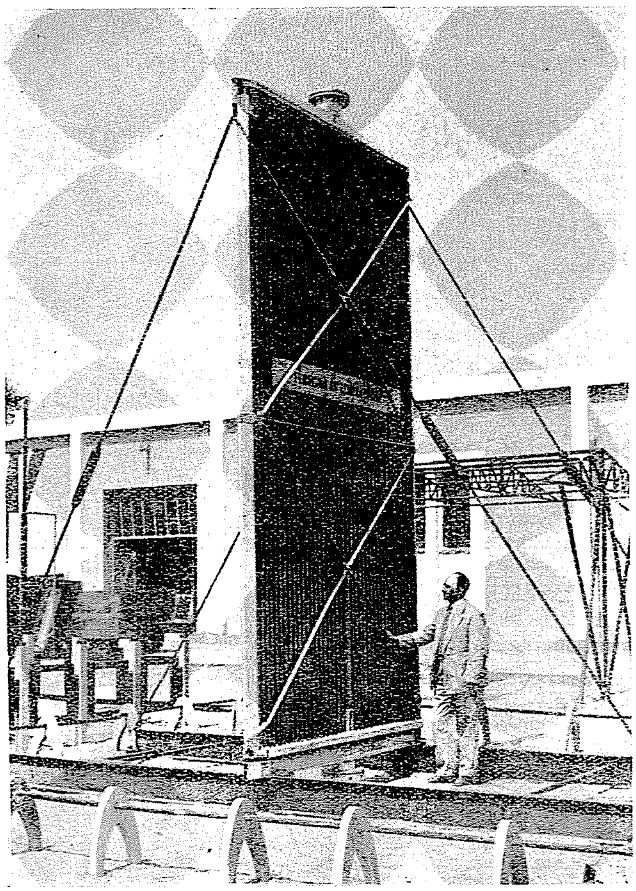


Fig. 11

The air-cooled condensing equipment "System Heller" in nuclear power stations

Costs for transportation of fuel to nuclear power stations being insignificant, such stations may be sited at all times in consideration of power distribution or other points of view — provided the limiting factor of cooling water supply does not influence the decision. It must be stressed, however, that water supply for nuclear power stations is a problem far more significant than for conventional thermal power stations since, due to the low temperature level of the heat removed from the reactor, the efficiency of thermal cycles in nuclear power stations is always materially below that of classic thermal power stations. Consequently, at identical effective electrical output, the heat to be rejected and with it the cooling water demand of a nuclear power station is considerably higher. As will be explained below in greater detail, the possible maximum reduction of the lower temperature level of thermal cycles greatly improves the output of a nuclear power station. That means that only a minimum increase in cooling water temperature is permissible which, again, results in an increased cooling water demand.

The air-cooled condensing equipment System Heller brings a radical solution to all these problems inasmuch as it has no cooling water demand whatsoever. Its particular advantage in nuclear power stations is the fact that its cooling water being circulated in a completely closed system and thus having no contact with the surroundings, the possibility of contamination through the cooling water is absolutely obviated.

As to the question of lower temperature limit already briefly outlined in the introduction, the following explanation should be given. In the development of condensing steam turbines the increasing of the vacuum behind the turbine represents an important stage. Until now steam turbines had been designed and built for a 0,07 or 0,05 ata condenser pressure and it was generally held that, due to the great exit losses, no higher vacua should be applied. Recent examinations, however, have revealed the very interesting fact that an increase of the exit steam velocity — provided that part of the exit losses is simultaneously recovered in appropriately shaped diffusers — may not only be effected free of losses but it may bring about even some improvement in the efficiency of the respective stage. Namely, the high velocity applied at the last stage, though increasing the exit losses, reduces at the same time the losses ensuing from the fact that with the lower velocity as applied hitherto, the admission on the blade ring was incomplete. Concurrently with augmenting the exit velocities, the turbine manufacturers were successful in building turbines with greater blade lengths. Thus, as a joint result of both factors, the condenser pressure at 100 MW capacity could be reduced to 0,02 ata, this being the pressure still practically governable from other points of view.

Operation at deeper vacua naturally involves higher costs but in view of the considerable saving in fuel, these additional costs are quickly recovered.

The points exposed above are of particular interest if an air-cooled condensing equipment System Heller is applied. With appropriate dimensioning of the air-cooled condenser, namely, even the lowest condenser temperatures may be achieved during the winter season, and winter is generally the season of highest loads. Economy calculations carried out in connection with a power station to be erected in the Federal German Republic showed that in consideration of the development in turbine construction and of the costs of the condensing system, the economical optimal vacuum, instead of 0,06 ata as thought originally, approximated the 0,02 ata value. In other words, due to the increased heat drop, the output of the unit will be higher by 5,5%, that is its capacity is increased from 100 MW to, 105,5 MW — at identical boiler output.

These results gain special interest when considered from the aspect of nuclear power stations. It is a known fact that the investment costs of nuclear power stations as referred to 1 kW capacity, are substantially higher than those of modern thermal power stations. Thus the improvement of the thermal efficiency is of primary importance, and a decrease in condenser temperature, as described in the foregoing, has a decisive influence. This improvement can be achieved by attaching to the nuclear power station an air-cooled condensing equipment with heat exchangers, overdimensioned compared to the usual sizes which, just on account of their excessive dimensions, will ensure a lower condenser temperature than the usual, in yearly average.

The economy calculations have proved that in up to date power stations operating at high pressure and multiple reheating, a 5,5 per cent increase in effective heat drop may be obtained by reducing the condenser pressure from 0,06 to 0,02 ata. In view of the fact that in nuclear power stations, due to their inherent low upper temperature limit, the effective heat drop does not attain even half of that in conventional thermal power stations, the absolute value of the increase in effective heat drop derived from the lower condenser pressure being identical, the percentual saving gained by the effective heat drop in nuclear power stations amounts to twice the value in conventional power stations.

For the sake of comparison, the thermal data of Calder Hall have been examined. These data have revealed that the savings achieved by the lower condenser pressure, that is, the additional output gained thereby, amounts to 12,9 per cent. In connection with nuclear power stations this naturally means that the plant efficiency at identical reactor output also increases by 12,9 per cent.

Since a very considerable part of the first costs is represented by the reactor costs, through increasing merely the heat exchanger surfaces, the efficiency of the whole nuclear power station might be improved and in a very economical manner indeed. Namely, through an additional investment of round 1,6 per cent — keeping the rest of expense items at the same level — the investment costs referred to 1 kW capacity could be reduced by 12,9 cent!

In the following table the results of our calculations are tabulated. In the first column the data concerning the 100 MW capacity equipment (for the Federal German Republic) can be seen, the second column has been computed on ground of the steam characteristics of Calder Hall. The calculations, within each type, were based on identical boiler output and identical reactor output, respectively.

Table II

	Conventional power station			Nuclear power station		
Condenser pressure, ata	0,06	0,04	0,02	0,06	0,04	0,02
Effective heat drop, kcal/kg	390	400	412	161	170	182
Capacity, MW	100	102,5	105,5	42	44,4	47,4
Increase of capacity, %	—	2,5	5,5	—	5,8	12,9

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