CORRESPONDENCE

Heat Transfer in Condensers

SIR,

The article by Commander Tribe in Vol. 5, No. 3, raises some problems in heat transfer in condensers which may be of interest.

A study of existing data is made simpler if the ' heat transfer coefficients' are converted to simple ' resistances '. No one would try to evaluate the current flowing in an electric circuit by reference to ' conductors ', and yet that is just what many engineers seem to do when dealing with heat transfer.

Considerable variation in experimental results may be found under different circumstances ; for instance the heat flow through a single tube in a laboratory test will bear little relation to the average rate of heat flow in the large nest of tubes of a condenser.

It is, however, possible to sort out the individual resistances by combining the data given by Guy & Winstanley in 1934, on the transfer between the vapour itself and the tube surface in a large number of condensers, with that given in McAdam's book *Heat Transmission* (1942), for the transfer through varying types of dirt or scale on the inside surface of a tube.

In the former report the authors say that it is not easy to allow for the formation of scale in the design stages. This article is not intended to dispute this statement, but rather to bring out the relative importance of the four resistances which impede the flow of heat, so that the cause of deterioration in performance of service may be more easily diagnosed.

Details of the individual heat transfer coefficients and the corresponding resistances in a condenser are shown in Table I. The figures given for heat transfer coefficients are based on a common area, viz. that of the outside of the tube, so that we can imagine the tube surface to be replaced by a single plane and forget the difference in area between inner and outer surface. The column showing resistance R gives the arithmetical reciprocal of h. It is easily seen that the overall resistance to heat flow is numerically equal to the sum of the individual resistances in series.

TABLE I

	h		$R = 1/h$
(*a*) Vapour to Tube	1,475	$\frac{B.Th.U.s}{ft.^2/hr/°F}$	0.69×10^{-3}
(*b*) Tube Wall (18 LSG) Cu Ni ...	5,000	,,	0.2×10^{-3}
Brass ...	16,000	,,	0.06×10^{-3}
(*c*) Scale : Very dirty	760	,,	1.32×10^{-3}
Mechanically cleaned	2,000	,,	0.5×10^{-3}
Sand blasted ...	4,200	,,	0.24×10^{-3}
(*d*) Tube or scale to water (V = 8 ft/sec.)	1,950	,,	0.51×10^{-3}

The figures given in this Table are subject to the following qualifications :—

(*a*) *Vapour to Tube.* It is not possible to give more than a suggestion of the many factors which affect this figure. Thus vacuum, thickness of condensing film, circulating water temperature and heat transfer co-efficient are all inter-related. More important is the effect of wasted space, ' dead ends ', etc. and the design practice is to rely on the overall experimental results. The figure of 1,475 B.Th.U/ft.^{2}/hr/°F. temperature difference is believed to be a fair estimate, which allows a little for falling off in performance. That is, R may be lower than the figure given, but not much.

(*b*) *Tube Wall.* These figures show the marked difference between two materials but in terms of resistance it is seen that they are relatively unimportant.

(*c*) *Scale.* Assuming tubes are kept in a ' mechanically cleaned ' condition the scale which soon forms on a new tube provides a very substantial part of the resistance to heat flow being more than double that of the copper nickel tube itself.

(*d*) *Tube to Water.* This is a function of water speed alone and McAdam's figure for heat transfer of 370 $V^{0 \cdot 8}$ has been used in preference to the lower figure for single tubes. R may therefore be under-estimated here.

If the figures in Table I are accepted as a basis for comparison the overall effect of a change in material, assuming no scale is present, is shown in Table II. The heat flow which is inversely proportional to R would in theory be improved by 11 % by changing from Cu Ni to Brass. On the other hand, if the suggested allowance for scale is made, the improvement deduced from Table III is only 8 %.

TABLE II (no Scale)

	R	%	R	%
Vapour to Tube	0.69	49	0.69	55
Tube Wall : Cu Ni	0.2	14	—	—
Brass	—	—	0.06	5
Tube to Water	0.51	37	0.51	40
Total R with no Scale	1.40	100	1.26	100

TABLE III (with Scale)

	R	%	R	%
Vapour to Tube	0.69	36	0.69	39
Tube Wall : Cu Ni	0.2	11	—	—
Brass	—	—	0.06	3.5
Normal Scale	0.5	26	0.5	28.5
Tube to Water	0.51	27	0.51	29
Total R with Scale	1.90	100	1.76	100

Comparison of the figures in Tables II and III shows that the deterioration in heat flow resulting from the formation of scale is 26 % to 28 % and we should make a clear distinction between chemically cleaned (or new) tubes and mechanically cleaned tubes.

Referring now to the article in Vol. 5, No. 3, and bearing these comparative figures in mind it seems that the ' fouling margin ' was really no more than a modest ignorance factor since practical results show that it was swamped by the change in material. There is an inherent weakness in the idea of a fouling margin in that it is based upon calculations of totally different factors which themselves are not exactly known.

On the other hand the importance of providing an increase in flow of circulating water is well illustrated by these figures. This appears to be a major disadvantage of ships fitted with scoops instead of full-sized separately driven main circulators. On the one hand a deterioration in vacuum leads to a reduction in the full ship's speed and hence a further reduction in circulating water flow, giving a cumulative curtailment in performance. On the other hand we usually have a sufficient margin of power in the main circulators to speed up the flow as fouling progresses.

It may be well asked 'what about new designs where weight and space is being cut to a minimum?' The figures given in the foregoing analysis offer only an approximate guide to the various factors affecting the heat flow in existing condensers and it is not suggested that simple arithmetic will solve the problem for new designs. The procedure recommended by the U.S. Heat Transfer Institute is to use overall 'clean tube' heat transfer rates shown in a family of curves for different sizes of tube and for varying water velocities, and then to apply a number of corrections for loading, sea inlet temperature and 'cleanliness'. This is justified on grounds of experience rather than arithmetic and cannot lightly be cast aside. As a matter of interest the correction for cleanliness is 0.85 on heat transfer rate, equivalent to an 18% increase in area of tube surface. Any bigger allowance would mean reducing the overall loading of the condenser and probably lead to no further improvement. A similar method is used for allowing the use of Cu Ni in the design by using a correction factor of 0.90. The nett overall rate obtained in this manner for a normally loaded condenser with tubes $\frac{5}{8}$ in. O.D. and with circulating water entering at 70°F. at 8 ft/sec. is 611 B.Th.U/ft.^{2}/hr/°F. for brass and 550 B.Th.U. for Cu. Ni.

In terms of resistance these figures become 1.64 and 1.82×10^{-3} respectively which are only slightly short of the figure given in Table III.

To sum up, it appears that the most practicable safeguard against loss of vacuum due to fouling is an adequate reserve capacity of circulating water, since to provide a proportionate margin of tube area would involve much extra weight with no certainty of results.

(*Sgd.*) J. I. T. GREEN,
Commander (*E*), *R.N.*

SIR,

I have read with interest Commander Tribe's article on Condenser Vacuum in your October, 1951, issue. This is a subject on which there is much woolly thinking and the more it is discussed the better.

My only criticism, and it is not a criticism of the article itself, is that the final graphs of cooling water flow might give the false impression that the circulators should be on main steam for full power. In a clean condenser the increased cooling water flow is not justified, the steam being better used in the main engines. In H.M.S. *Chevron*, for instance, after retubing with aluminium brass tubes the following figures were obtained :—

	P.	*S.*	*P.*	*S.*
Circulator Nozzle Box Pressure ...	210	210	Shut Off (On Trailing Nozzles)	
Circulator Speed	600	600	300	300
Condenser Sea Inlet Temperature ...	62	62	62	62
Condenser Sea Outlet Temperature	80	81	86	88
Vacuum	28.6	28.5	27.9	28.0
Main Engine Receiver Pressure ...	240	240	248	248
Main Shaft Speed	314	315	320	320

Thus, shutting off the circulators gave an extra 6 r.p.m. on the shafts.

With a dirty condenser, of course, this does not happen and the vacuum may well drop several inches if the circulators are trailed. This is in fact a crude, but not recommended, way of telling if the condensers are dirty.

(*Sgd.*) T. WHEELDON,
Commander (*E*), *R.N.*

SIR,

In his letter on the subject of heat transfer in condensers, Commander Green has put the effect of changing condenser tube materials into correct perspective. The resistance through the metal walls of heat exchanger tubes is the smallest of the components of the total resistance to heat transfer. Nevertheless, there is such a very great difference between the thermal conductivity of cupro-nickel and aluminium brass that the effect of changing from cupro-nickel to aluminium brass upon total resistance to heat flow, is by no means unimportant, particularly in a condenser with an inadequate fouling margin. The actual overall effect estimated as a percentage depends upon the assumption made in the calculation as to the resistance of the scale in the tubes ; my own calculations made during the investigation in question, indicated that the gain in heat transfer by changing from cupro-nickel to aluminium brass tubes in the condensers of *Emergency* Class destroyers is of the order of 10-15%, which agrees with Commander Green's Table II.

I agree with Commander Green that the provision of a fouling margin in condensers is not as simple a matter as may be supposed, and that a margin of circulating water quantity is the best solution to the problem. This was taken into account when the decision was made to fit scoops to the main circulating water systems in *Emergency* Class destroyers instead of changing the tube material. If, however, the scoops had not proved successful in augmenting the circulating water quantity in these ships without undue appendage resistance, then a change in condenser tube material would have been the only practical means of increasing the fouling margin. The provision of greater circulating water pump capacity in an existing installation in which the additional surplus auxiliary exhaust cannot be utilized is, of course, out of the question.

Referring to Commander Wheeldon's letter, it is mentioned in the article in Vol. 5, No. 3, that optimum full power performance can be obtained in tropical waters in *Emergency* Class destroyers fitted with scoops, with the trailing nozzles of the circulators only in use. The reasons given by Commander Wheeldon for the gain in power in the instance quoted by him (*Chevron*) are not complete, however. In *Emergency* Class destroyers *steaming at full power*, the design of the later stages of the L.P. turbines is such that full advantage cannot be taken of vacua over 26.5 in Hg, and the use of steam on the main nozzles of the circulators to obtain vacua higher than this is wasteful. Higher vacua are, of course, most profitable at lower powers.

(*Sgd.*) R. H. TRIBE,
Commander (*E*), *R.N.*

SIR,

With reference to your correspondent's letter in Vol. 6, No. 1, of the *Journal*, the rest of the story of the s.s. *Pine Hill* may be of interest.

When H.M.S. *Liverpool* relieved H.M.S. *Gambia* at Port Said, this vessel, which had just come up the Canal under tow, was one of the commitments 'turned over'. *Gambia's* staff had already succeeded in cutting about halfway through one propeller blade by drilling with a ratchet and drill post, and after the available methods had been reviewed, this was continued.

A large oxy-acetylene set was available, and was tried, but despite an alarming consumption of gas, was useless because of the high conductivity of the metal. It did not even make any impression on the thin webs left between the drilled holes, which were cut with a cold chisel. Arc cutting was rejected because of the limited power available on board.

After both blade tips had been removed, it was found that one blade, although well clear at T.D.C., still fouled the rudder at B.D.C., and a further 'slice' had to be removed. This task of cutting was so exasperating that the idea of trimming ship and fitting the spare propeller carried on board was seriously contemplated.

It was then found that the rudder post (about 12 in. diameter, solid steel), had been set about 16° when the propeller was damaged. New asymmetric links for connecting the steering engine quadrant to the tiller were made and fitted to compensate for this.

After various minor repairs to auxiliaries, and a survey by divers, a sea trial was run to the satisfaction of Lloyd's surveyor. The ship was then sent on her way rejoicing, most of the rejoicing being done by the weary artificers of the afloat repair party.

(*Sgd.*) H. L. PRATT,
Lieutenant (*E*), *R.N.*