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Influence of Ship Vibrations on Heat Exchangers

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Abstract. The effect of vibrations on heat transfer has been described. The study made on a double pipe counterflow heat exchanger clearly shows that vibrations of heat exchangers cause increase in heat transfer coefficients. The maximum increase in overall heat transfer coefficient achieved is 165 per cent. In places where vibrations are inherently present like in ships, the onboard heat exchangers can make use of this phenomenon and increase the effectiveness of heat exchangers.

Notations

A	Area of heat transfer, m^2
C_p	Specific heat at constant pressure K Cal/Kg°C
$LMTD$	Log mean temperature difference
m	Mass rate of flow Kg/hr
ΔT	Temperature difference °C
T	Temperature °C
U	Overall heat transfer coefficient K Cal/hr m² °C
O	Oil
w	Water
1	Inlet
2	Outlet

1. Introduction

During recent years there has been considerable interest in the effect of vibratory phenomena on heat transfer. In many a case, heat transfer equipments are themselves in a state of vibration or vibrations can be set up in them without affecting their performance. For example, cryogenic oxidizer supply tank in a liquid fuel rocket on a ship, commercial motor vehicle, an aircraft in flight, etc.

Pak[1], *et al.* have experimentally studied the effect of vibrations on convection heat transfer from a horizontal cylinder where the entire system, both the heated surface and fluid are simultaneously subjected to vibrations. They observed improvements in heat transfer due to vibrations, the maximum increase being 200 per cent. They also obtained a dimensionless correlation between Nusselt number and measured parameters. Lemlinch[2] studied the effects of vibration on heat transfer involving natural convection from electrically heated wires, of three different diameters, subjected to transverse vibrations in air. Marked improvement in the coefficient of heat transfer even to the extent of quadrupling the film was obtained by vibrations of 39 to 122 cycles per second. In addition, a pair of dimensionless correlations based on a vibrational Reynolds number were presented for vibration in air or other diatomic gases. An approximate extension to other fluids was also proposed. R. M. Fand and E. M. Peebles[3] reported that physical mechanism of interaction between free convection from a heated horizontal cylinder and horizontal transverse vibrations is essentially the same whether the vibrations are acoustically or mechanically induced.

2. Heat Exchangers in Naval Vessels

In naval vessels where heat has to be extracted from certain places to keep the system in peak operation, the efficiency of the heat exchangers, their size and weight become a matter of vital importance. The simplest type of heat exchanger in use is the lubricating oil cooler. This is generally of the forced convection type using sea water as the coolant through the tube stack and the lubricating oil, as the liquid to be cooled, being forced through the shell.

The design of the lubricating oil cooler is based on certain factors governing the velocities of flow through the shell and tube and these are normally specified in General

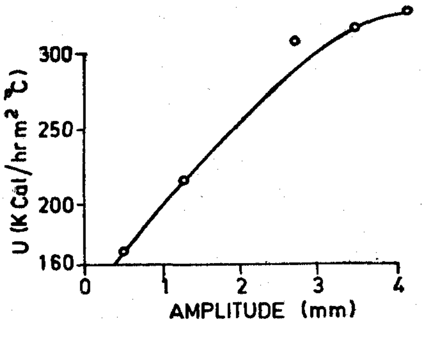

Figure 1. Amplitude scan—frequency 30 Hz (Const), Re No. oil 527 (Const), Re No. water 9588 (Const).

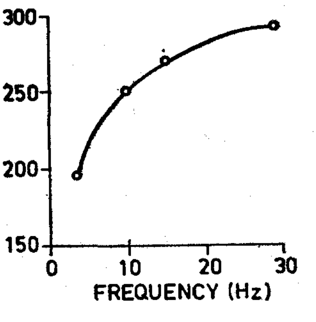

Figure 2. Frequency scan—amplitude 4.95 mm (Const), Re No. oil 527 (Const), Re No. water 11186 (Const).

Marine Engineering specifications. The present study describes the effect of vibrations on a double pipe heat exchanger where a hot and cold fluid exchange heat. The scope of this study can extend to many naval vessels where such heat exchangers are used.

In order to determine the range of frequency and amplitude in which the experimental investigation had to be conducted, reference was made to Goldrick's[4] works. Table below gives values of frequencies and amplitudes encountered in certain class of ships as determined by vibration generator tests conducted in the David Tayler Model Basin[5].

Table 1.

Sl. No	Name of ship	Type	Frequency of vertical flexural mode (Hz)	Amplitude (mm)
1.	*Niagara*	Transport	7.5	1.77
2.	*Charles S Ware*	Destroyer	6	2.8
3.	*EJ Kulas*	Ore Carrier	6	0.182
4.	*CA Paul*	-do-	7.3	2.4
5.	*Pere Marguette* 21	Carferry	9	1.58
6.	*Old Colony Mariner*	Dry Cargo	4.5	—
7.	*Northampton*	Cruiser	8.5	0.24
8.	*Staten Island*	Ice Breaker	12	1.15

The Navy's Military Standard—Mechanical vibrations of ship epuipment[6] specifies vibration between 5 and 33 cycles per second, at which endurance tests on equipments are to be run. The experiment was therefore conducted in the frequency range of 0 to 30 Hz and amplitude range of 0 to 4 mm so that the experimental values correlate well with the actual values obtained on ships.

3. Experimental Investigation

An experimental investigation was carried out to find the effect of transverse vibrations on convection heat transfer in a double pipe counterflow heat exchanger.

For a counter flow heat exchanger,

$$LMTD = \frac{(T_{0_1} - T_{w_2}) - (T_{0_2} - T_{w_1})}{\log_e \left[\dfrac{T_{0_1} - T_{w_2}}{T_{0_2} - T_{w_1}} \right]}$$

$$U = \frac{m_0 C_{p_0} \Delta T_0}{A(LMTD)} = \frac{m_w \, C_{pw} \, \Delta \, T_w}{A \, (LMTD)}$$

The mass flow rate of water can be recorded under steady state conditions by measuring the flow over a period of time. This being lesser than the mass of oil flowing, the temperature increase from inlet to outlet is easily recordable. Since the water is passed through the tube surrounded by the shell fluid, the loss due to radiation from the latter cannot affect the inlet and outlet temperatures of water and thus the value of U itself. Hence the ultimate equation used is :

$$U = \frac{m_w C_{pw} \, \Delta T_w}{(LMTD) \, A}$$

To evaluate the effect of vibration on the overall heat transfer coefficient U, values of m, ΔT, $LMTD$, amplitude and frequency of vibrations are recorded. Sufficient time is allowed for steady state conditions to be reached before recording are made. Also, the readings are taken for both vibratory conditions and non-vibratory conditions.

Water, as coolant, flows through inner tube and hot oil flows through the annulus between inner and outer tube. The heat exchanger was suitably insulated and mounted in a frame. A vibrator was connected to the shell of the heat exchanger to induce transverse vibrations of different frequencies and amplitudes. The frequency of 4 Hz to 30 Hz and amplitude of 0.5 mm to 4.35 mm were used. Oil flow rate was varied in laminar region whereas water flow rate was varied both in laminar and turbulent regions. Suitable temperature gauges were used to record temperatures of oil and water at inlet and outlet of the heat exchanger. Valve arrangements and flow meters were used to vary and record the flow rates of oil and water. Oil was heated by electric immersion heaters with a relay arrangement to maintain the oil temperature in the oil bath at the desired temperature level.

The experiment was conducted in five main stages as follows: (*i*) No vibratory conditions, (*ii*) Amplitude scan from 0.5 mm to 4.35 mm, (*iii*) Frequency scan from 4 Hz to 30 Hz, (*iv*) Water flow rate variation from Re No. 2394 to 23976, and (*v*) Oil flow rate variation from Re No. 342 to 760.

During stage (*iv*) and (*v*) the frequency and amplitude of vibration were kept at 30 Hz and 2 mm respectively. The graphical analysis of the results are given in Figs. 1–6.

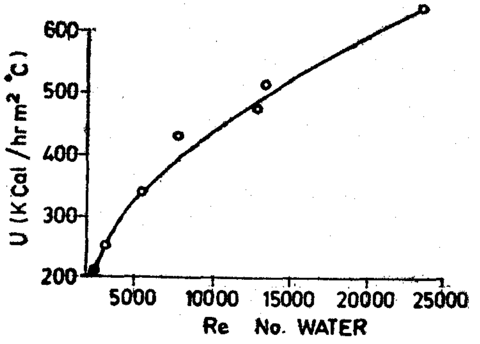

Figure 3. U *vs* Re No. water—frequency 30 Hz (Const), amplitude 2 mm (Const) & Re No. oil 434 (Const).

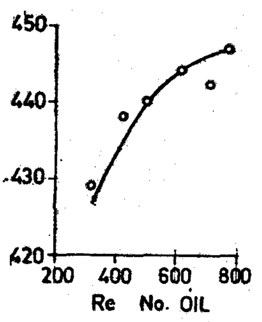

Figure 4. U *vs* Re No. oil—frequency 30 Hz (Const), amplitude 2 mm (Const), & Re No. water 7990 (Const).

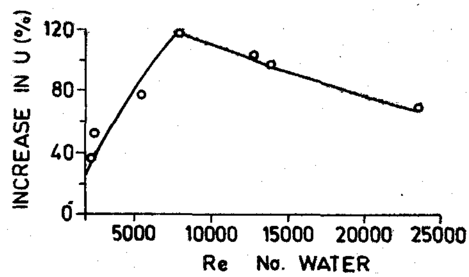

Figure 5. Percentage increase in U *vs* Re No. water & Re No. oil 494 (Const).

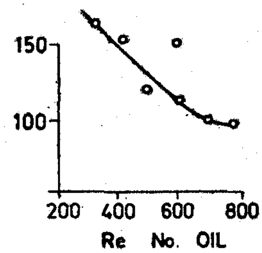

Figure 6. Percentage increase in U *vs* Re No. oil & Re No. water 7990 (Const).

4. Observations

The following observations are made :

(*a*) There is a definite increase in the overall heat transfer coefficient due to induced vibration on the heat exchanger.

(*b*) Rate of increase in the overall heat transfer coefficient is substantial upto a Re No. 8000 for water, remains virtually constant till about 12500 and then decreases gradually. Turbulence definitely sets in above this rate of flow and effect of turbulence due to flow offsets the effect due to vibration.

(*c*) As the oil flow rate in the shell is increased, there is an increase in overall heat transfer coefficient, but its rate of increase shows a gradual decreasing trend.

5. Conclusion

It can be concluded that vibrations cause a definite improvement in overall heat transfer coefficient. For a viscous fluid, the rate of improvement is quite substantial for low Re number of flow, and in the case of less viscous fluid like water, the improvement is considerable right upto the beginning of turbulent zone. In the present investigation, the maximum increase in overall heat transfer coefficient achieved is 165 per cent.

In places where vibrations are inherently present as in ships, it may be possible to utilise the existing vibratory conditions suitably converted to optimum values of frequency and amplitude. The advantage could be either reduction in size and weight of heat exchanger or a greater heat transfer capacity. There is good scope to carry out further study for machinery on ships.

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