IMPROVED HEAT TRANSFER BY MEANS OF STEAM INJECTION IN A SHELL & TUBE HEAT EXCHANGER

O. K. Kaunde

Institute of Production Innovation, University of Dar es Salaam
P.O. Box 35075, Dar es Salaam, Tanzana

ABSTRACT

When designing a heat exchanger, one aims at attaining high heat transfer rates so as to minimise heat transfer area and therefore the overall cost. This paper presents a method of improving the overall heat transfer coefficient of a conventional shell and tube heat exchanger. The method involves injecting steam into the process fluid as it enters the heat exchanger thus effecting mixing of fluid as it travels along the exchanger. Tests carried out using this technique showed a significant increase in the overall heat transfer coefficient values.

INTRODUCTION

Shell and tube heat exchangers are used in the majority of chemical processes, for the purpose of heating or cooling of fluids. In such an equipment the heat transfer rate, Q is given by an equation;

$$Q = U_o . A . LMTD \quad (1)$$

The overall heat transfer coefficient, U_o, is influenced by two forms of heat transfer; conduction and convection. By definition convection proceeds mainly as a result of mixing. Fluid mixing in a conventional shell and tube heat exchanger appears to be achieved at high fluid velocities, i.e. for turbulent flow (Re symbol 179 \f "Symbol" \s 12¶§ 21,000), but it is not attained by streamline flow(1).

A method is being introduced in this paper of increasing fluid mixing in a shell and tube heat exchanger through injection of steam, consequently increasing the overall heat transfer coefficient. This method forces fluid mixing not only at high speed of fluid but also at smaller values of fluid velocity.

DESCRIPTION OF THE EXPERIMENT

Fig 1 shows a test rig that was used to study the effect of motive steam to the heat transfer rates. The test rig consisted of a shell and tube heat exchanger constructed of stainless steel. A small steam generator (total volume of approximately 10 litres) was placed underneath the exchanger, such that steam so produced could be admitted into the bottom end of the exchanger and mix with the process fluid flowing on the tube side of the exchanger. For this particular experiment rape-seed-oil was used as the process fluid. On leaving the distributor, steam expands and due to density difference between steam and the oil, the former tends to raise at a faster speed than the later thus causing fluid mixing in the tube. On the shell side of the exchanger high pressure steam was admitted and was the major heat source to the oil.

The test rig also consisted of a double pipe heat exchanger for the purpose of cooling the oil as it leaves the shell and tube heat exchanger. The oil storage tank was supplied with coil through which steam or cold water could flow for the purpose of controlling temperature of oil before it start the cycle.

Rotameters (calibrated for water flow measurements) were used to adjust flows for the oil and steam. The actual flow rates of oil were found by weighing oil collected in the glass vessel over some known time intervals. Likewise the flow rate of motive steam was found by considering the amount of water consumed from the steam generator over the duration of the experiment.

Thermocouples were used for temperature measurements of oil at the inlet and outlet of the exchanger.

It should be mentioned at this point that the same test rig could also be used for deodorisation experiments of edible oils. The equipment can be open to the vacuum system for this purpose.

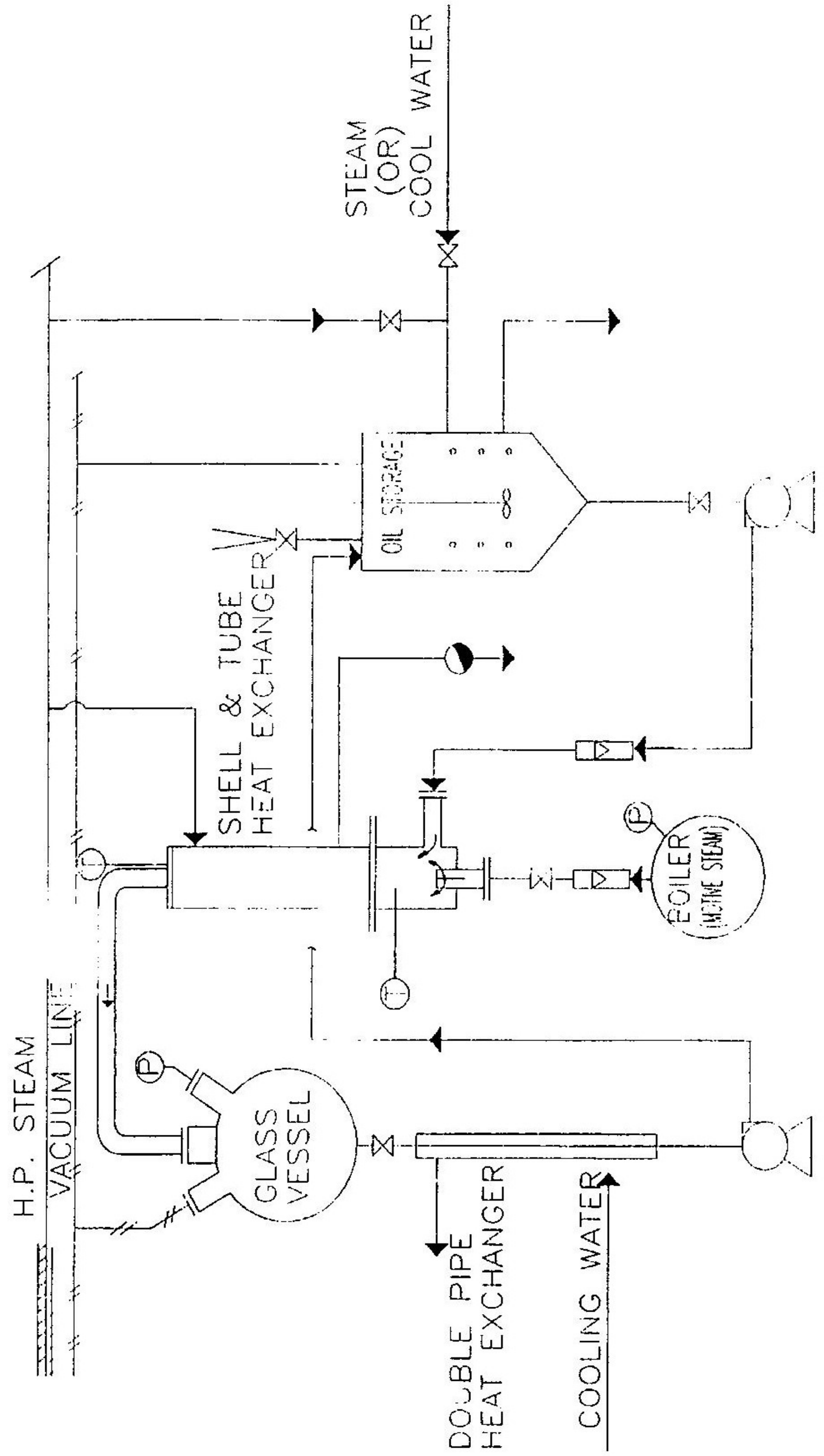

FIG 1. STEAM POWERED HEAT EXCHANGER ARRANGEMENT

SUMMARY OF PROCESS / TECHNICAL DATA

Heat exchanger:

Type:	Shell and tube
Overall dimensions; shell height	1.1 m
shell diameter	0.165 m
Heat transfer area (7 tubes of 3/4" pipe),	Ao 5.58 m^2

Steam (shell side of exchanger):

Pressure	9.5 Bar Gauge
Temperature	177 ^{o}C

Motive stem (tube side of exchanger)

Pressure (saturated steam)	1.013 Bar Gauge
Temperature	100 ^{o}C
Flow rate	1.0 kg/h (Maximum)

Oil (Rape seed oil)

Flow rate, M	300 kg/h (Maximum)
Inlet temperature to exchanger	25 ^{o}C
Outlet temperature	110 ^{o}C
Specific heat of oil, Cp	2.05 kJ/kg^{o}C

RESULTS

Overall Heat Transfer Coefficients (U_o)

The overall heat transfer coefficient, U_o, for each run of the experiment was calculated by using the heat balance equation;

$$Q = U_o . A . LMTD = M . Cp . \Delta T \qquad (2)$$

Steam Ratio (R)

Steam ratio, R, as defined in this paper is the ratio of mass flow rate of motive steam to mass flow rate of oil flowing through the tubes of the exchanger expressed as a percentage;

$$R = \frac{m_{injected.steam}}{m_{oil}} * 100\% \quad (3)$$

A graph of steam ratio against the overall heat transfer coefficient - with flow rates of oil as a parameter is as shown in Fig 2. The graph shows that for a given oil flow rate the overall heat transfer coefficient increases as the steam ratio (or rather flow rate of motive steam) in the tube increases. This is a direct consequence of injecting steam into the exchanger. Steam induces mixing effect of fluid in the tube, thus increasing the inside film coefficient, in turn increasing the U_o values. It can also be thought that a fraction of heat carried by the steam-bubbles is transferred into the bulk of the oil causing some increase in temperature of oil leaving the exchanger.

Fig 2 also shows that at a given steam ratio, U_o values are higher as fluid flow rate (M or V) increases, again a fact explained by mixing effect in the tubes. Within the range of data collected the curves for constant oil flow rate (constant M or V) could be approximated by straight lines, suggesting that a linear relationship exist between the oil flow rate and attainable U_o values.

Considering the slopes of these lines it is found that U_o values are more sensitive to changes in steam ratio for high values of liquid velocities.

The curves for constant oil flow rates intercept the abscissa at points corresponding to values of heat transfer coefficients of a normal shell and tube exchanger (i.e. condition when no motive steam is flowing through the tubes).

APPLICATION OF THE TECHNIQUE

In general the technique of improving heat transfer by steam injection as proposed in this paper can be used to heat any fluid provided its properties and/or quality may not be distorted considerably if brought into contact with live steam or due to the presence of traces of steam condensate.

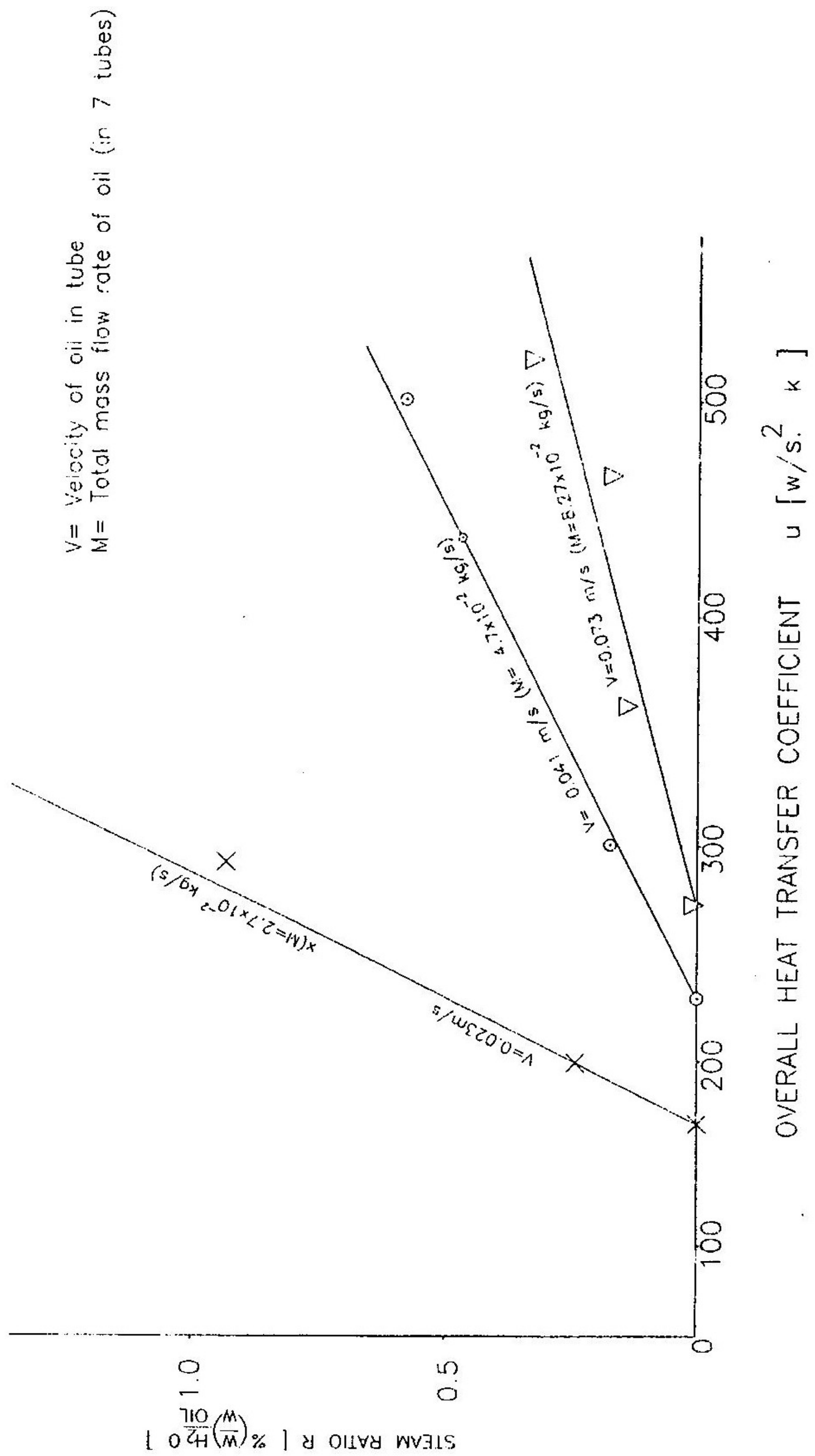

FIG 2. STEAM RATIO Vs OVERALL HEAT TRANSFER COEFFICIENT

One specific example of such a process is the deodorisation of edible oils. Deodorisation is one of the stages in the refining of edible oils. It involves injecting steam into the preheated oil preferably under vacuum so as to distil the volatile substances that impart odour to the oil[3]. Traditionally these two operations (heating and steam injection) are carried out in two separate pieces of equipment. However with the technique proposed in this paper the two operations can be carried out in a single piece of equipment, i.e. the shell and tube heat exchanger.

Although it is not the intention of this paper to go into the details (chemistry) of deodorisation process, it is interesting to report that deodorisation of oil was also affected in the cause of the experiment. At the end of each run oil was found to be of superior quality as revealed by test results for some properties of the oil (free fatty acids, peroxide value, colour and taste).

CONCLUSION

This paper has presented a technique that can be used to improve heat transfer coefficient in a shell and tube heat exchanger through injection of live steam in the process fluid. By attaining high values of heat transfer coefficients the size of exchanger to accomplish a given duty is reduced, consequently reducing the cost of the exchanger. Also, the two processes; preheating of fluid and steam distillation, operations which would otherwise be carried in two separate pieces of equipment may be carried in a single unit, thus minimising the capital as well as running costs for the equipment.

In practice the technique may be used in processes involving heating of fluids provided a small amount of condensate that may dissolve in the fluid will not be harmful to the quality of the product. One specific example of such a process is the deodorisation of edible oils.

ACKNOWLEDGEMENTS

This research was conducted while the author was on Professional Training with Simon Rosedowns Ltd in Hull U.K. The author wishes to thank the company, and the staff in Research and Development Department for their co-operation. Thanks are also due to the DAAD for sponsoring my

practical training.

NOMENCLATURE

A	Outside surface area of pipe	m^2
Cp	Specific heat of fluid (oil)	kJ/kg.K
hi	Inside film coefficient	W/m^2K
ho	Outside film coefficient	W/m^2K
L	Length of heat exchanger tube	m
k	Thermal conductivity of metal	W/m^2K
LMTD	Long Meant Temperature Difference	^oC
M	Mass flow rate of oil in the exchanger tube	kg/s
R	Steam ratio	-
ΔT	Change in temperature	^oC
U_o	Overall coefficient of heat transfer	W/m^2K
V	Velocity of oil through exchager tube	m/s
Q	Rate of heat transfer	W

REFERENCES

1. D.Q. Kern, *Process Heat Transfer*, McGraw Hill International Book Company, 1950
2. R.H. H Perry and D.Green, *Perry's Chemical Engineers' Hand Book* 6th ed., 1984, pp 10-8 to 10-19)
3. V. Young, *Processing of Oils and Fat*, Applied Science Publishers, London 1980 (chapter 7)

The manuscript was received 24th April 1994 and accepted for publication 6th December 1994