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STUDY OF THE HEAT TRANSFER IN THE SUPERHEATER REGION OF BOILER

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ABSTRACT

The superheater zone of the boiler is the convective heat transfer region of the boiler, that is the heat in this region mostly transferred by the convection between the flew gases outside and steam inside tubes. The factors that effected the heat transfer rate and heat transfer coefficient in the Mosiab power station boiler (980000kg/hr capacity under pressure of 175bar) at its superheater is studied here. The super heater is divided into two parts, primary and secondary super heater. Each part is divided into many zones depending on the pipe size and material.

The effect of boiler load mass flow rate of steam on the heat transfer rate, heat transfer coefficient, steam temperature is studied. It is concluded that as the load on the boiler increased the heat transfer rate is also increased and the heat transfer coefficient. The heat transfer coefficient in secondary superheater is less that that in the primary. The reduction in mass flow rate of steam increases the wall temperature of tubes because of low capacity of water to receive heat.

الخلاصة

تعتبر منطقة المحمص من المرجل منطقة ذات انتقال الحرارة بالحمل نتيجة لانتقال الحرارة العالي بواسطة الحمل في هذا المكان بين غازات نواتج الاحتراق من الخارج بخار الماء داخل الأنابيب. درسْت في هذا البحث العوامل التي تأثر على معدلات انتقال الحرارة ومعمل انتقال الحرارة في منطقة المحمص من مرجل محطة كهرباء المسيب الحرارية (ذو السعة 980000كغم/ الساعة ويعمل تحت ضغط 175 بار). يقسم المحمص إلى قسمين المحمص الابتدائي والمحمص الثانوي. وكل جزء مقسم إلى عدة مناطق اعتمادا على حجم الأنابيب ومعدنها.

تم دراسة تأثير كل من حمل المرجل ومعدل التدفق لبخار الماء على معدلات انتقال الحرارة و معامل انتقال الحرارة ودرجة حرارة البخار. واستنتج منها بأن زيادة الحمل تؤدي إلى زيادة معدل انتقال الحرارة ومعامل انتقال الحرارة. وكان معامل انتقال الحرارة في منطقة المحمص الثانوي أقل مما في المحمص الابتـدائي. و التقليل في معدل التدفق للبخار خلال المرجل يؤدي إلى ارتفاع درجة حرارة الأنبوب بسبب انخفاض سـعة البخار لسحب الحرارة.

KEY WORD
Boiler, Super heater, Performance, heat tranter.

INTRODUCTION

The boiler is the most important part of steam power plants. It is a system that transfers heat from the products of combustion to water and produces hot water or steam. The steam or hot water must be delivered in the desired condition with respect to pressure, temperature and quality at the desired rate. The energy stored in steam is converted in to kinetic energy in the turbine then in to electrical energy in the power generator .The steam from the turbine is condensed in the condenser and circulated to the boiler. The boilers can be classified due to their operation pressure, capacity, type of fuel, water circulation, material of construction, and firing method. The boilers in general are constructed from the following components:- combustion equipment, furnace, superheater, reheater, economizer and air heater, and boiler auxiliaries.

The problems connected with heat transfer that effected the performance of the boiler were studied by many researchers. Cohen et.al. (1967) , studied the nucleated boiling from surface covered with porous magnetite deposits. The number of nucleation site in the case of fouled surface was considerably greater than for clean surface. In the single phase forced connective region the fouled surface temperature exceeds that of clean surface by 16 °C. Nucleation occurs at low heat flux in the case of the fouled surface and for heat flux about 1.2MW/m^2 the temperature of the fouled surface falls below that of clean surface. Macbeth (1971), studies the temperature elevation caused by various types of thickness of crude deposit with high pressure, force convection boiling of water. The result shows that the temperatures elevation varies with heat flux for different deposits. Taborek et al. (1972), show that increasing in flow velocity results not only in higher heat transfer coefficient and smaller equipment size but, in most streams is decreased tendency to word fouling and, therefore lower maintenance cost. On the negative side is higher pump and energy cost. Krause el al. (1976), examined the combined firing of refuse and fuel in boiler furnace of the Municipal Electric plant of Columbus, Ohio. The boiler is rated at 150,000 Ib at steam per hr, but normally operates at 125,000 Ib of steam per hr with an electric out put of 12.5MW. They concluded that increasing either the metal temperature or the gas temperature shortens the lifetime of a carbon steel boiler tube. They found for permissible corrosion rate of 250μm/yr for 15 year tube life, that carbon steel will not perform satisfactorily in an environment of refuse combustion products having low sulfur content for gas temperatures greater than 620°C when the metal temperature exceeds 205°C. When the sulfur contend of the refuse were increased to about 1.7 weight percent, then the allowable metal temperature for 150year tube life could be increased to 315°C with a gas temperature maintained at 650°C, or the allowable gas temperature could be increased to 760°C with a metal temperature maintained at 205°C.

This study is to investigate the effect of many variables on the heat transfer coefficient of the primary and secondary superheater of the Mosaibe power station boiler. This boiler is water tube, subcritical pressure (P<210bar), high capacity (980000kg/hr), liquid and gas fuel, and naturally circulated with special steel constructed.

ANALYTICAL METHOD

The mathematical model, which will be analysis consisting of tube with heat transfer from flue gases to steam in tube through the tube wall. The over all heat transfer equation will be derived here for primary and secondary superheater.

The effect of temperature on the physical and thermal properties included here in this study to limit the errors.

Physical Properties OF Flue Gas

In general the flue gas is mixture of many gases. The molar fraction of these construction are calculated as follows (Van Wylen 1999)

$$X_{N2} = 0.79 \times \dot{m}_a \tag{1}$$

$$X_{CO2} = S \times (\frac{44}{12}) \times \dot{m}_f \tag{2}$$

$$X_{H2O} = S \times (\frac{18}{2}) \times \dot{m}_f \tag{3}$$

$$X_{O2} = \{(0.21) \times \dot{m}_a\} - \{(S \times \frac{32}{12}) + (S \times \frac{32}{4})\}\dot{m}_f \tag{4}$$

$$X_{total} = \sum N_i \tag{5}$$

The mole fraction is defined as the numbers of mole in the component to the total numbers of moles.

$$Y_{gi} = \frac{X_i}{X_{total}} \tag{6}$$

The calculation is done in wide range of temperature; by using excel software all data for the gas properties are fit, by using polynomial equation as follows:

$$\Phi (T) = K_0 + K_1 T^2 + K_2 T^3 + K_3 T^4 = \sum_{i=0}^{3} K_i T^i \tag{7}$$

Φ any property.

Physical Properties of Steam

The properties of steam is varied with the variation of the load because the pressure of operation is different, so from **Fig. (1)**, **Fig. (2)**,and **Fig. (3)** that shows the properties of steam at different pressure and temperature. By tabulated these data from curves, by excel software and also the properties is written in the form of polynomial equation as:

$$\Phi (T) = K_0 + K_1 T^2 + K_2 T^3 \tag{8}$$

The properties are viscosity, density, thermal conductivity and specific heat for different load (Arthur 1965).

Table (1) Steam properties at (175) bar

	K_0	K_1	K_2
μ	$5.1*10^{-5}$	$-7.77*10^{-8}$	$6.3*10^{-11}$
C_p	197048.1	-51.84175	0.347
K	0.639666	-0.00144122	$9.06*10^{-7}$
ρ	561.2871	-1.1139322	$5.97*10^{-4}$

Table (2) Steam properties at (168) bar

	K_0	K_1	K_2
μ	$5.1*10^{-5}$	$-7.77*10^{-8}$	$6.3*10^{-11}$
C_p	203185	-540.22	0.3649
K	0.5721	$-1.3*10^{-3}$	$8*10^{-7}$
ρ	494.15	-0.9662	0.0005

Analysis The Flue Gas Temperature

Flue gas temperature at each zone its most important to continuous the calculation of this work, by the know flue gas temperature in the inlet and outlet of each zones these lead to finding the physical properties of the gases. A simple of calculation is illustrated in appendix. This example show the inlet and outlet temperature to the primary and secondary superheater, by assuming linear gradient by this will get all temperature in each zone.

A simple of calculation where done to illustrate the method of analysis the performance of the superheater region of the boiler.

The superheater region of boiler in order analyzing is divided into two parts: -

1- The primary superheater
2- The secondary superheater

The following measurement is taken to the primary superheater at (MCR) load (Yunus 1998).

Mass flow rate of gas ($\dot{m}_g$) =283 Kg/s

Inlet temperature of gas (T_{g1}) =1602 K

Outlet temperature of gas (T_{g2}) =1459 K

Log mean temperature difference =854.73 K

Mean steam temperature $= \dfrac{T_{sin} + T_{sout}}{2}$ =678.5 K

Flue gas temperature =LMTD + mean steam temperature

All properties of gas are measured at this temperature such as density, viscosity, thermal conductivity etc.

To calculate the performance of the superheater it is very important to calculate the heat transfer coefficient inside and outside the tube of boiler.

Primary Superheater

Outside heat transfer coefficient

The outside heat transfer coefficient is the coefficient of heat transfer between the flue gases flow in the boiler and the tube of boiler (Yunus 1998, and Holman 1992).

It can be assumed as flow around tube and (Re) value (4000 <Re< 40000)

$$Nu=0.193\ Re^{0.618}\ Pr^{1/3} \tag{9}$$

Inside heat transfer coefficient

The flow inside the tubes with (Re >2000) is turbulence flow so

$$Nu=0.023\ Re^{0.8}\ Pr^{0.4} \tag{10}$$

And all properties of steam were at film temperature

The heat transfer through the tube wall

Heat transfer by conduction through the wall and the thermal resistance is:

$$R=\frac{d_o}{2\pi K}\ Ln\frac{d_o}{d_i} \tag{11}$$

And the over all heat transfer coefficient is

$$U=\frac{1}{R_i+R_o+R} \tag{12}$$

Secondary Superheater

In the secondary superheater the heat transfer on the tube (inside and out side) can be calculated as follows:

Outside heat transfer coefficient

The flow is assumed as flow on bank of tubes in staggered arrangement (Holman 1992) **Fig. (4)** show tube arrangement.

$$Nu=0.39\ Re^{0.581}\ Pr^{1/3} \tag{13}$$

$$Nu=0.395\ Re^{0.58}\ Pr^{1/3} \tag{14}$$

To calculate

$$V_{max}=\frac{S_n}{S_n-d_o}\times V \tag{15}$$

And then the heat transfer coefficient can be calculated as

$$h_o=\frac{NuK}{d_o} \tag{16}$$

Inside heat transfer coefficient

It can be calculated by using eq.13

And

$$R_i=\frac{A_o}{A_i h_i} \tag{17}$$

Heat transfer coefficient through the wall

This coefficient is as calculation mode and its resistance is

$$R=\frac{d_o}{2\pi K}\text{Ln}\left(\frac{d_o}{d_i}\right) \tag{18}$$

And the over all heat transfer coefficient is

$$U=\frac{1}{R_o+R_i+R} \tag{19}$$

DISCUSSION

The convection section in boiler represented by super heater, which divided in, to two sections, Primary superheater and secondary superheater. The primary superheater was divided into eleven zones and secondary superheater into thirteen zones according to metal type and the difference in outside and inside diameter. In order to investigate the effect of the input variables and operation condition four different load were taken (MCR, 100%, 60%, 40%), and four different input variables were selected due to their relevance to the analysis done in this work. The selection variables were the mass flow rate, fuel flow rate, excess air and gas flow rate.

The output results were represented as heat transfer rate and over all heat transfer coefficients for both primary and secondary superheater with zones, which are indicated, as numbers in the figures showing these profiles.

Fig. (5) shows heat transfer rate in primary superheater with zone which are variable from zone to anther because of the differences in value of inlet and outlet steam temperature in each zone. The figure show two heat transfer rate in each load, which is the same variation but different values because of the different in mass flow rate in each load.

Fig. (6) shows two heat transfer rate with zone and for different load but in secondary superheater, from the comparing the value between the two figures which show that heat transfer rate in secondary superheater is less than primary superheater because of different in temperature encountered and because of this reasons they used different metal in each zone and part.

Fig. (7) shows the over all heat transfer coefficient for primary superheater with different load and illustrated that heat transfer coefficient is increase with increasing of load because the increase of load needs more fuel flow rate, air flow rate and gas flow rate. **Fig. (8)** shows over all heat transfer rate in secondary superheater in different load, from comparing the value between primary and secondary superheater it is shown that the overall heat transfer coefficient in secondary superheater have higher values than that in primary superheater because of the different in the effective area, that the and secondary superheater have bigger area than that of primary superheater.

The general effect of mass flow rate of steam is to increase heat transfer rate in the convection zone and this mostly effect on tube wall temperature.

Figs. (9, 10, 11) and **(12)** show the effect of decreasing mass flow rate of steam on tube wall temperature in primary superheater at different load. The decrease in mass flow rate steam at constant heat transfer rate will increase tube wall temperature, because of decrease in the mass flow rate of steam will decrease the heat transfer coefficient and it is shown mathematically that it will increase tube wall temperature. **Figs. (13, 14, 15)** and **(16)** show the same effect but in secondary superheater and for the same reasons tube wall temperature will increase when mass flow rate of steam increase.

The increase in tube wall temperature more than design value will reduce the life of super heater tube because of excessive stresses lead tube to crack and failure.

CONCLUTION

Heat transfer rate is changed with load variation. it is function of boiler load. The heat transfer rate in the secondary superheater is less than that at the primary superheater due to the decreasing of the temperature difference between the steam and flue gas.
The heat transfer coefficient is also function of the load, that ti is increasing as the load increase. The heat transfer coefficient in the secondary super heater is higher than that in the primary because of its less transfer area.
The mass flow rate of steam will increase the wall temperature of tube and decrease the heat transfer rate in brimary and secondary super heater.

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NOMENCLATURES

symbol	Definition	Unit
$\dot{m}_a$	Mass flow rate of air	Kg/sec
$\dot{m}_f$	Mass flow rate of fuel	Kg/sec
ρ	Density	Kg/m^3
μ	Viscosity	Kg/m.s
Cp	Specific heat at constant pressure	KJ/kg.K
h	Heat transfer coefficient	W/m.°C
K	Thermal conductivity	W/m.K
K_n	Polynomial constant for term n	
LMTD	Log mean temperature difference	°C
Nu	Nusselt number	
Pr	Prandtle number	
R	Thermal resistance	$K.m^2/W$
Re	Reynolds number	
S	Content of fuel	
T	Temperature	K
T_g	Gas temperature	K
U	Overall heat transfer coefficient	$W/m^2.K$

V	Velocity	m/sec
V_{max}	Maximum velocity	m/sec
X	Number of moles	
Y	The mole fraction	

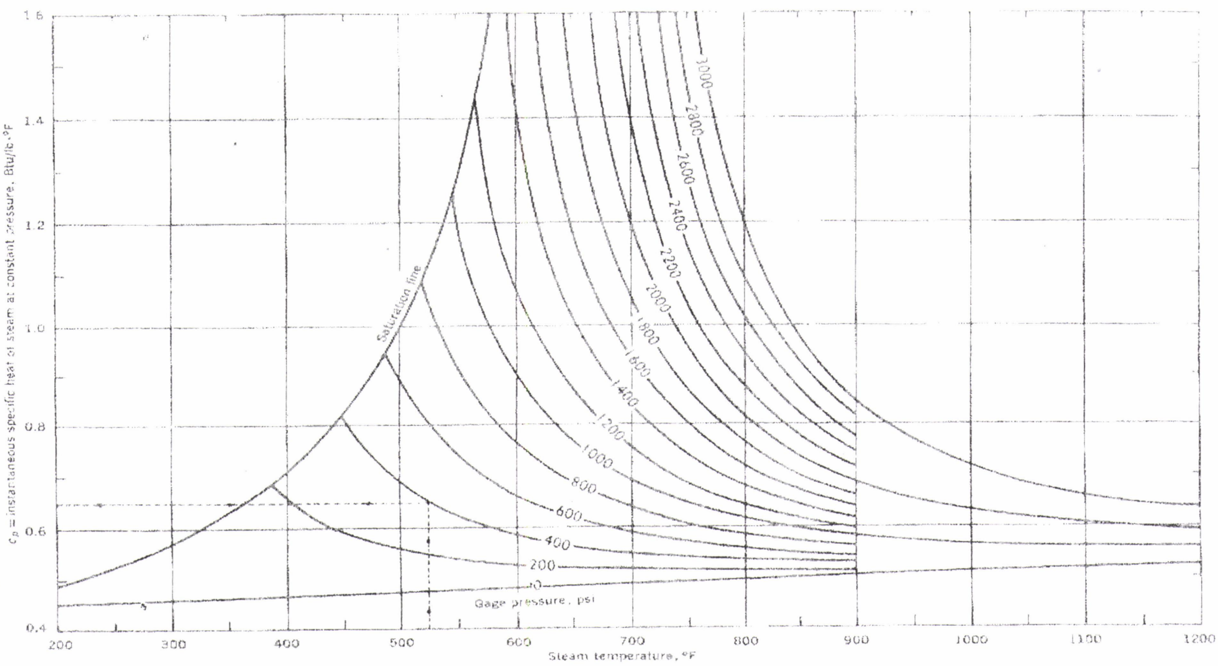

Fig. (1) Effect of Temperature and Pressure on Specific of Steam

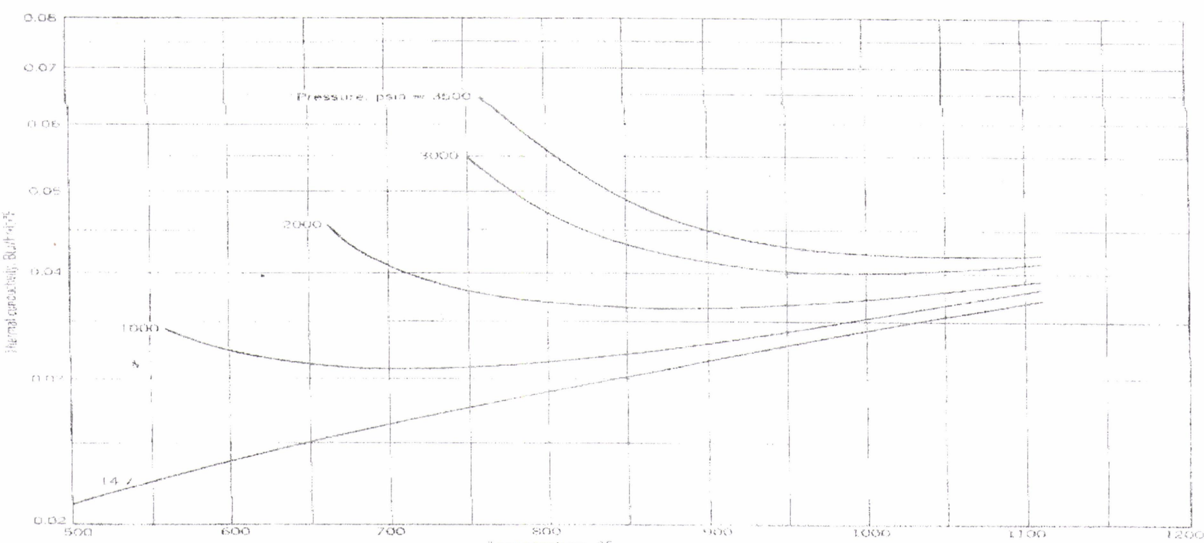

Fig. (2). Effect of Temperature and Pressure on The Thermal Conductivity of Steam

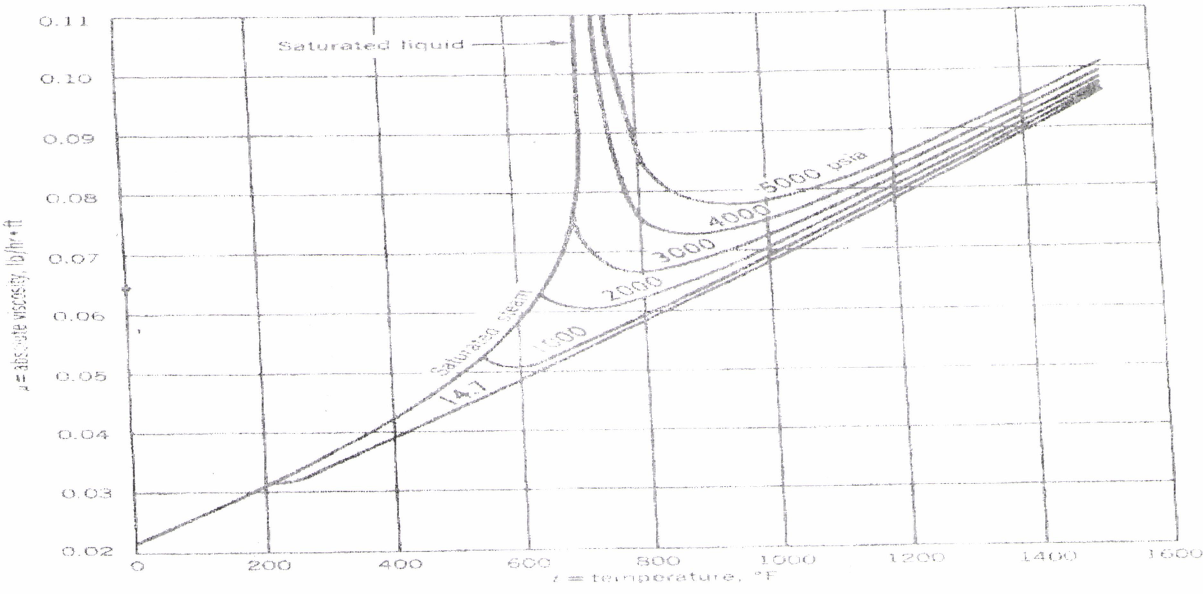

Fig. (3) Effect of Temperature and Pressure on The Viscosity of Steam

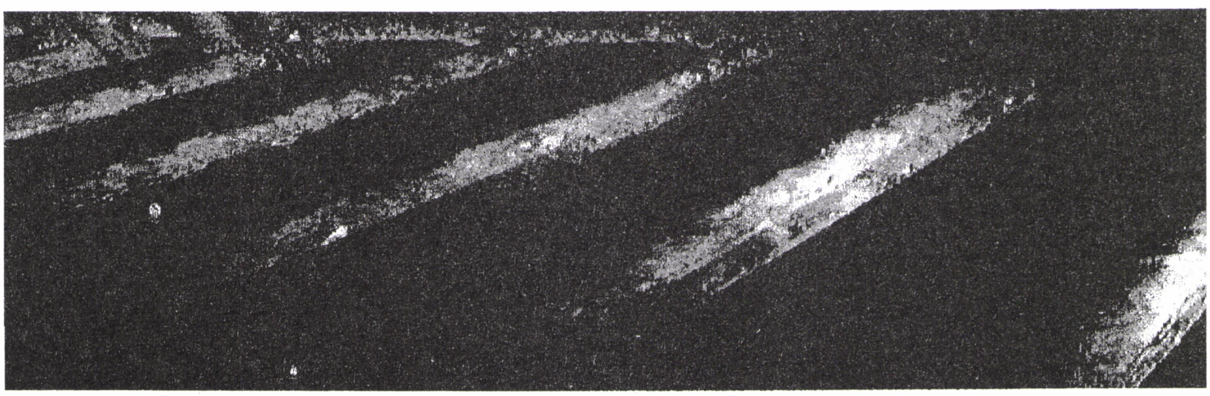

Fig. (4) The Secondary Superheater Arrangement Tube

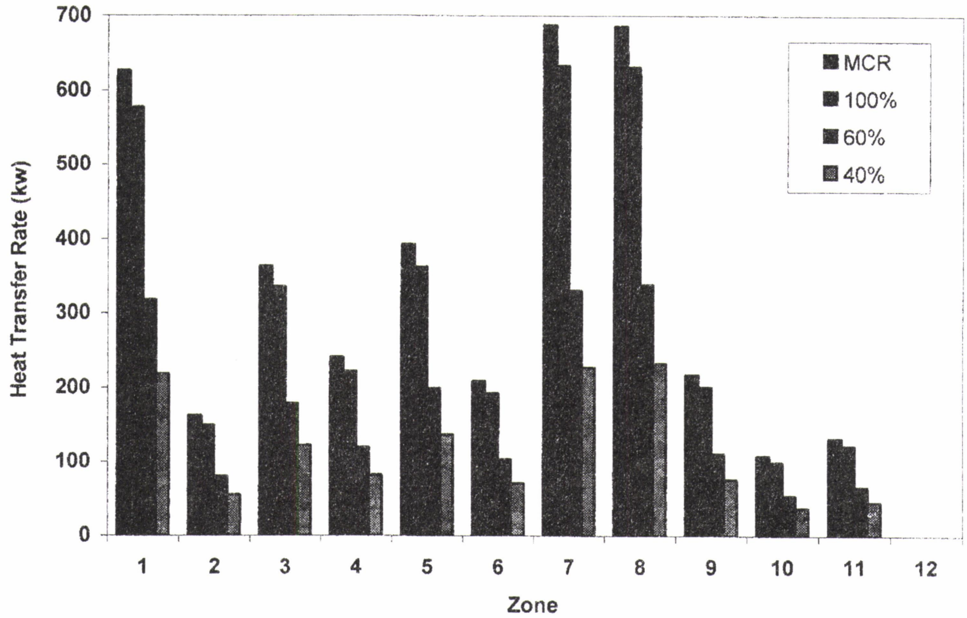

Fig. (5) Heat Transfer Rate in Primary Superheater in Different Load with Zone

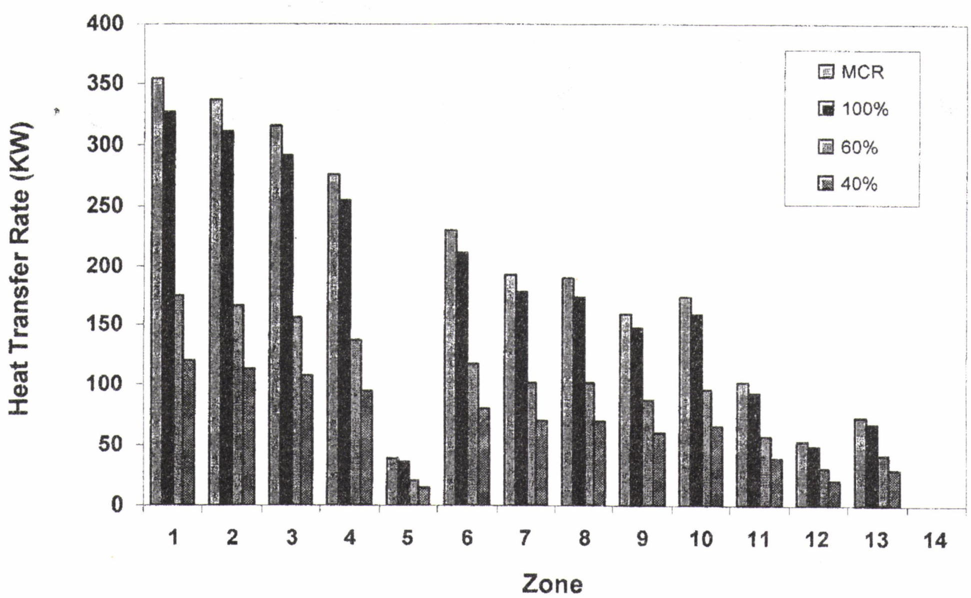

Fig. (6) Heat Transfer Rate in Secondary Superheater in Different Load with Zone

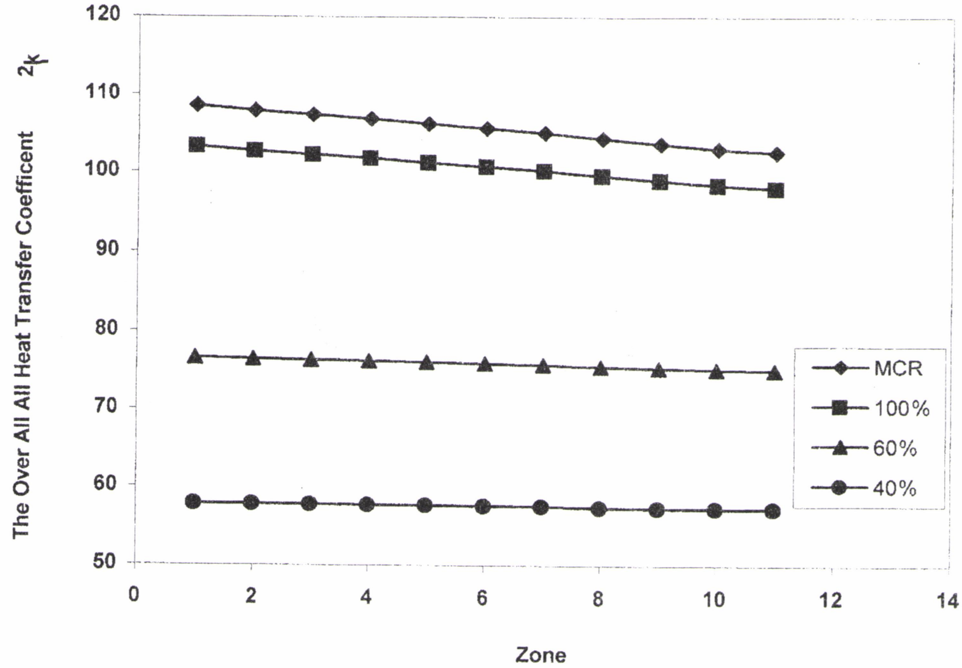

Fig. (7) The Over all Heat Transfer Coefficient of Primary Superheater in Different Load with Zone

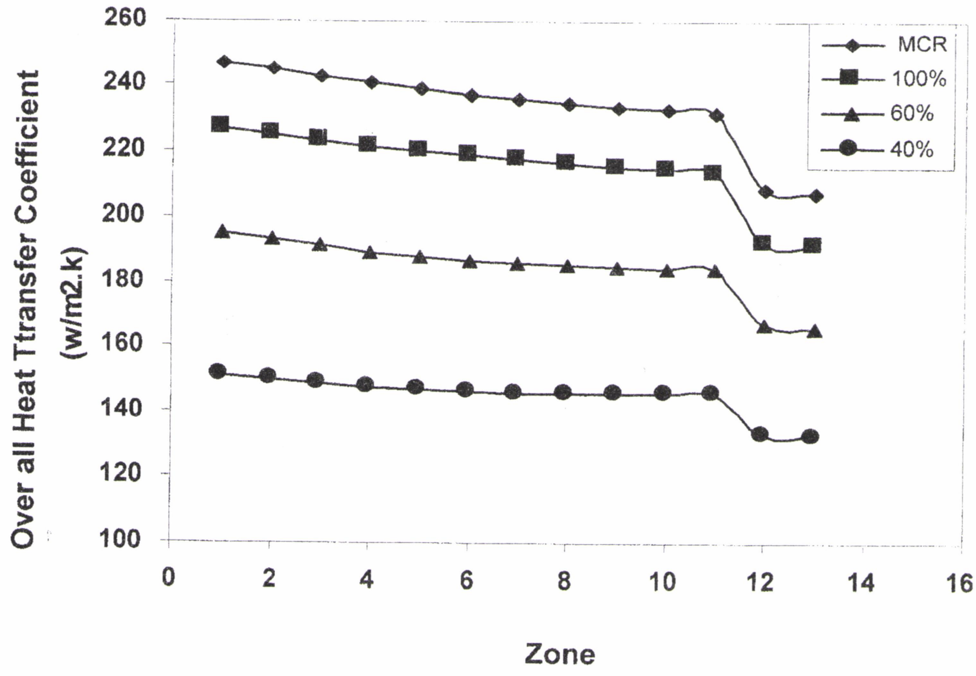

Fig. (8) The Over all Heat Transfer Coefficient of Secondary Superheater in Different Load with Zone

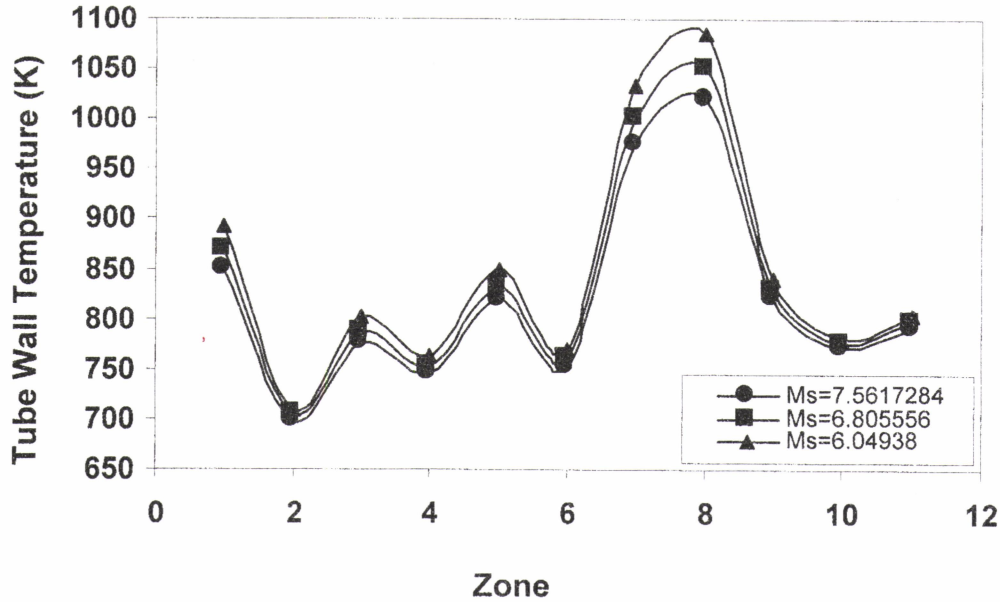

Fig. (9) The Effect of Steam Flow Rate on Tube Wall Temperature in Primary Superheater at MCR Load

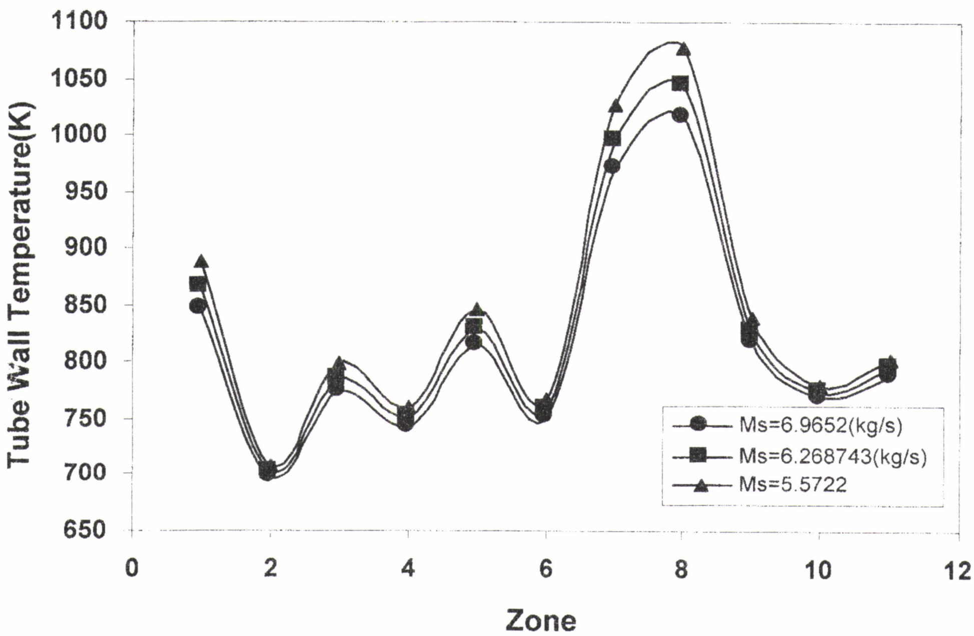

Fig. (10) The Effect of Steam Flow Rate on Tube Wall Temperature in Primary Superheater at 100% Load

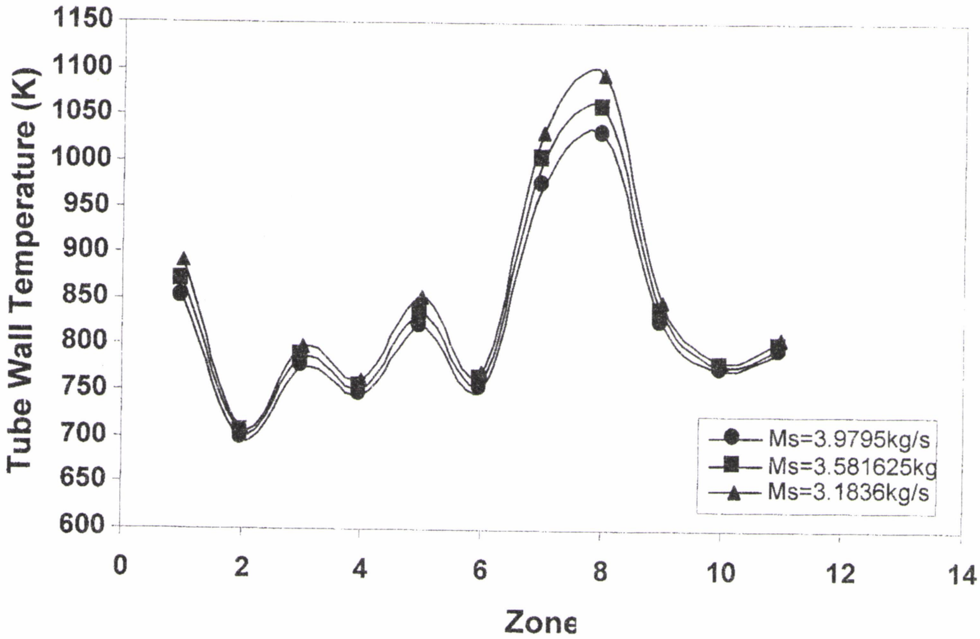

Fig. (11) The Effect of Steam Flow Rate on Wall Tube Temperature in Primary Superheater at 60% Load

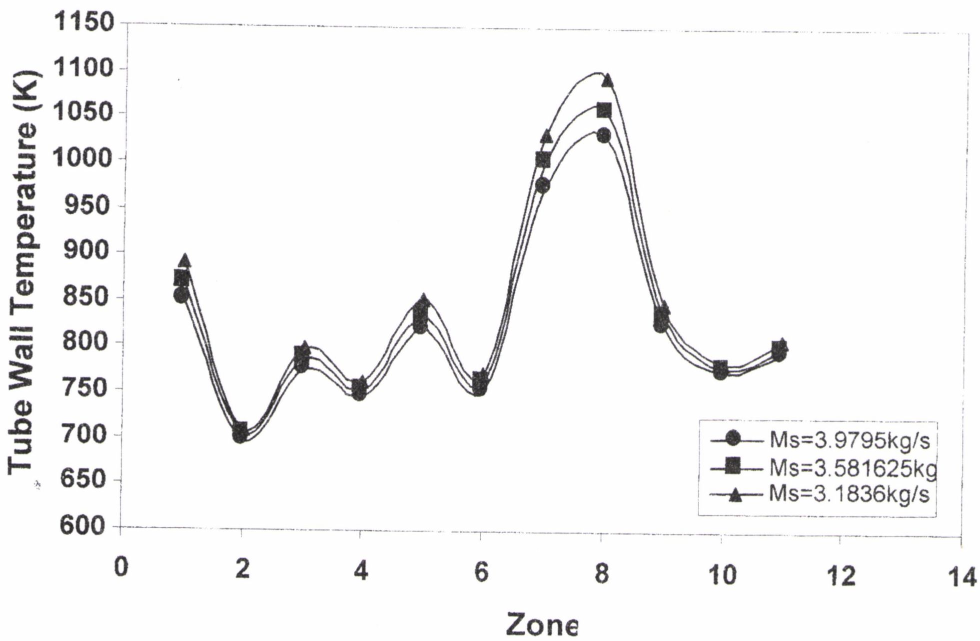

Fig. (12) The Effect of Steam Flow Rate on Wall Tube Temperature in Primary Superheater at 40% Load

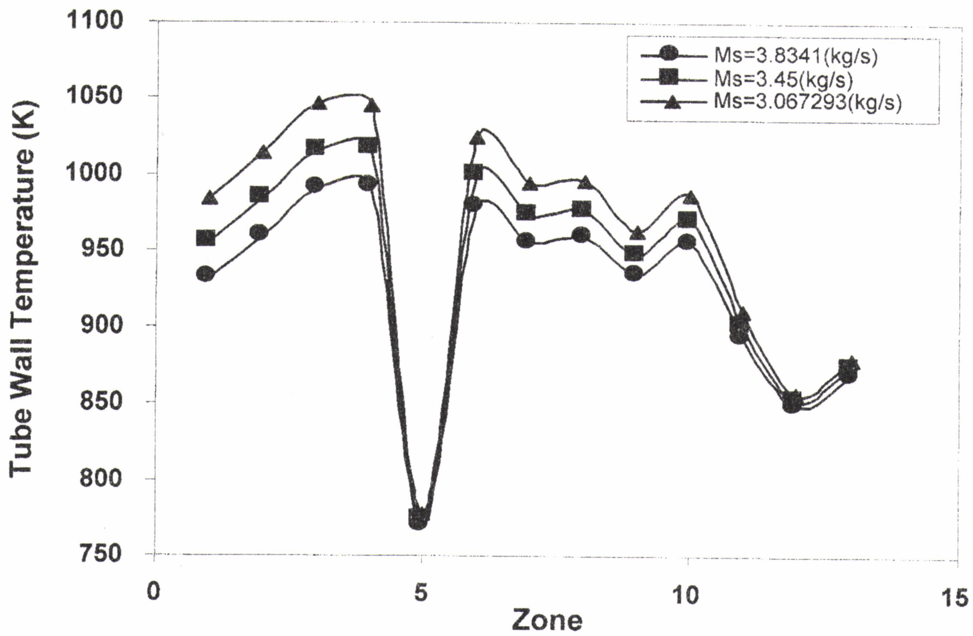

Fig. (13) The Effect of Steam Flow Rate on Wall Tube Temperature in Secondary Superheater at MCR Load

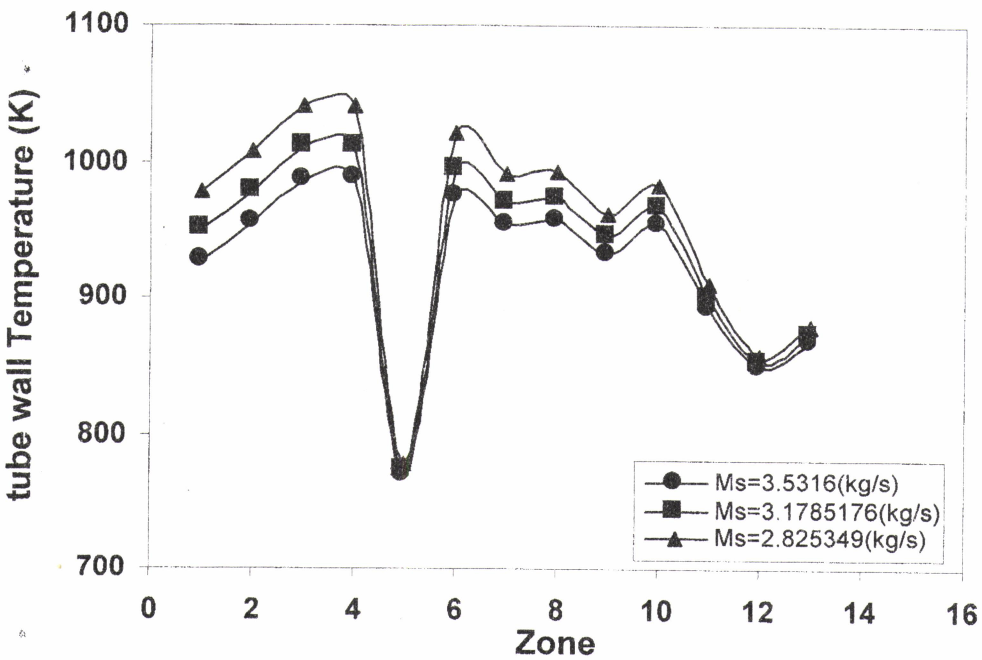

Fig. (14) The Effect of Steam Flow Rate on Tube Wall Temperature in Secondary Superheater at 100% Load

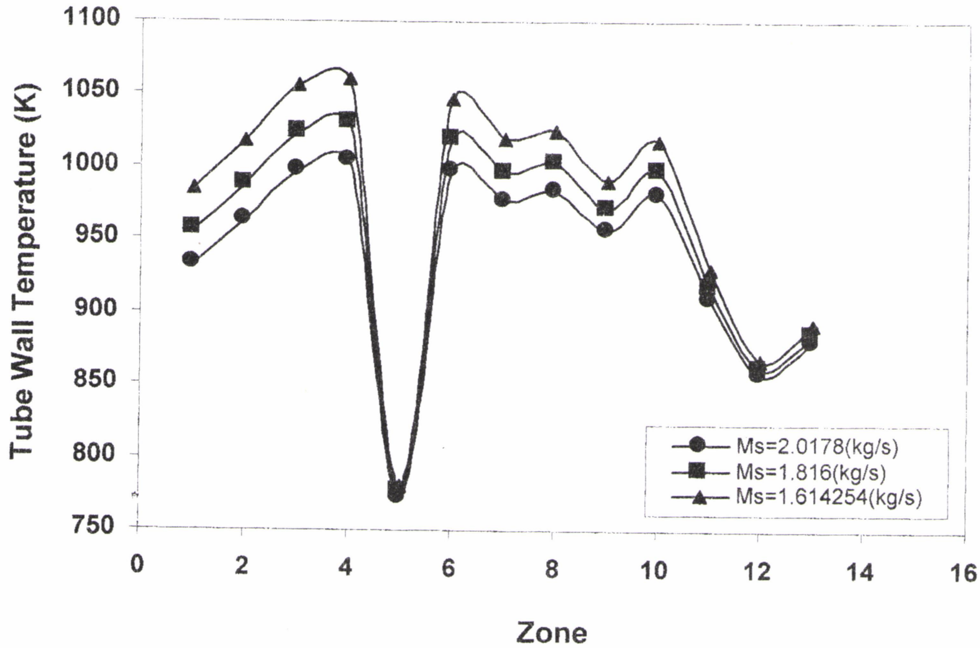

Fig. (15) The Effect of Steam Flow Rate on Wall Tube Temperature in Secondary Superheater at 60% Load

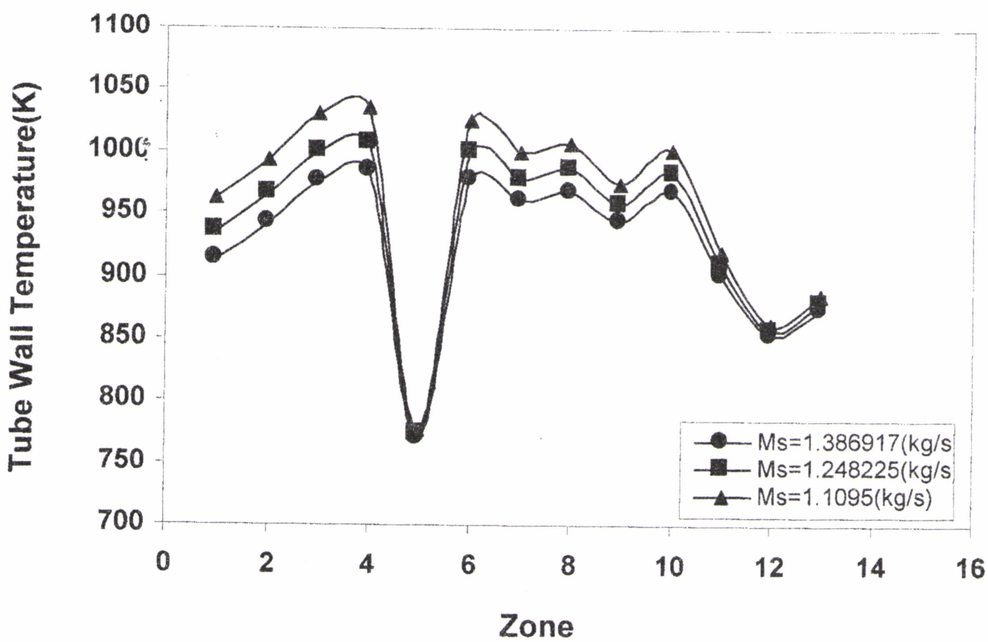

Fig. (16) The Effect of Steam Flow Rate on Tube Wall Temperature in Secondary Superheater at 40% Load