# Experimental Investigation of Heat Transfer Characteristics of Calcined Petroleum Coke Fin-and-Tube Waste Heat Exchanger

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**Abstract:** The experimental system of waste heat utilization exchanger, installed in the tank calcined furnace, was built. The heat transfer coefficient of heat exchanger, temperature distribution of calcined petroleum coke and utilization ratio of waste heat were systematically studied. The results showed that with the increase of calcined petroleum coke velocity, the heat transfer coefficient of heat exchanger increases. The utilization ratio of waste heat increases first and then decreases. With the increase of water velocity, the heat transfer coefficient of heat exchanger increases. Compared with light-and-tube heat exchanger, the heat transfer performances of fin-and-tube heat exchanger increase. The average steam producing rate and the average utilization ratio of waste heat increase. The average temperature of calcined petroleum coke in heat exchanger outlet decreases. The uniformity degree of temperature in heat exchanger outlet increases.

**Keywords:** Calcined petroleum coke, fin-and-tube, heat transfer characteristic, steam producing rate, utilization ratio of waste heat, waste heat exchanger.

## 1. INTRODUCTION

Petroleum coke is calcined to remove the fugitive constituent through high temperature, which becomes calcined petroleum coke after complete carbonized. The calcined petroleum coke is one of the important basic raw materials. It is widely used in producing anode of aluminum electrolytic, graphite electrode, recarburizer, industrial silicon and other carbon products.

The China's production capacity of calcined petroleum coke is largest in the world, above 70% of which is produced in tank calcined furnaces [1-5]. The temperature of calcined petroleum coke discharged from tank calcined furnaces is up to 1000 °C, and the waste heat of it has high potential to be utilized. The calcined petroleum coke would be cooled in waste heat exchanger after discharged from tank calcined furnaces. The oxidation combustion reaction could be prevented.

Heat transfer of the solid material had been studied in some fields. Barati [6] introduced some waste heat recovery methods of the high temperature steel slag. The waste heat of the high temperature steel slag is utilized by rotary cylinder atomizing method and air nozzle method [7-9]. Generation of fuels based on the utilization of the slag thermal energy in endothermic reactions has been recently studied. As a heat carrier and storage medium, the use of hot slag has been proposed [10, 11].

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Investigation related to the utilization technology of calcined petroleum coke waste heat, however, has been very limited. In this paper, heat transfer characteristics of calcined petroleum coke fin-and-tube waste heat exchanger were studied by the experimental system of waste heat utilization exchanger.

## 2. EXPERIMENTS

The experimental system of waste heat utilization exchanger was built in Weifang Lianxing Carborn Co., Ltd. The heat transfer experiments were carried out by the experimental system (Fig. **1**). The experimental system is composed of fin-and-tube waste heat exchanger, calcined petroleum coke supply system, water circulation system and measurement system.

Fin-and-tube waste heat exchanger: Fin-and-tube waste exchanger includes outer heat exchanger and inner heat exchanger. The axial fin is equipped with heat exchanger tube. Its structure is shown in Fig. (**2**).

Calcined petroleum coke supply system: The experimental system is installed in the tank calcined furnace. The high temperature calcined petroleum coke is directly supplied from tank calcined furnace.

Water circulation system: This system is composed of cooling pond, pumps, valves, sight glass, drum and so on. There is a FLUXUS F601 ultrasonic flowmeter in the heat exchanger inlet, which is used for measuring the water flow. Its measuring accuracy is ±0.5%. Its repeatability is 0.15%. Its measuring velocity range is from 0.01 m/s to 25 m/s. There is a WSM-D two-phase flowmeter in the heat

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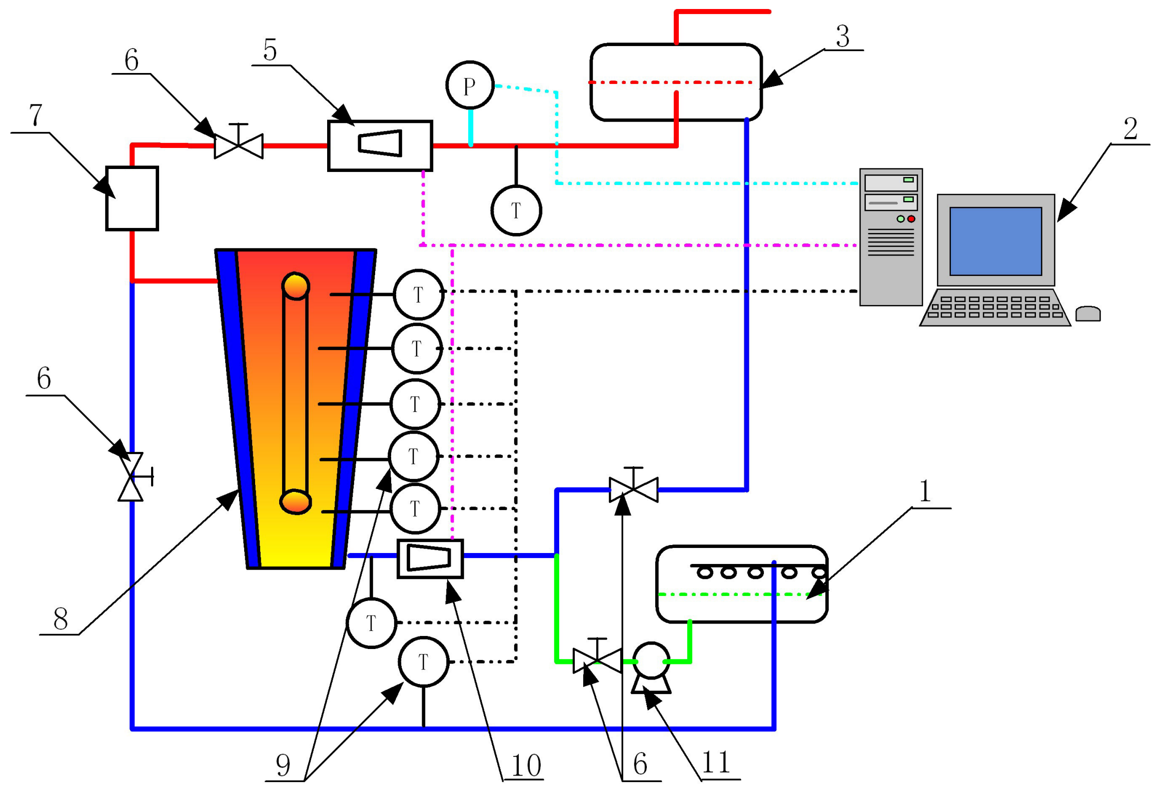


**Fig. (1).** Schematic of experimental system (1. cooling pond; 2. data acquisition system; 3. drum; 4. pressure sensor; 5. two-phase flowmeter; 6. valve; 7. sight glass; 8. fin-and-tube waste heat exchanger; 9. temperature sensor; 10. flowmeter 11. pump).

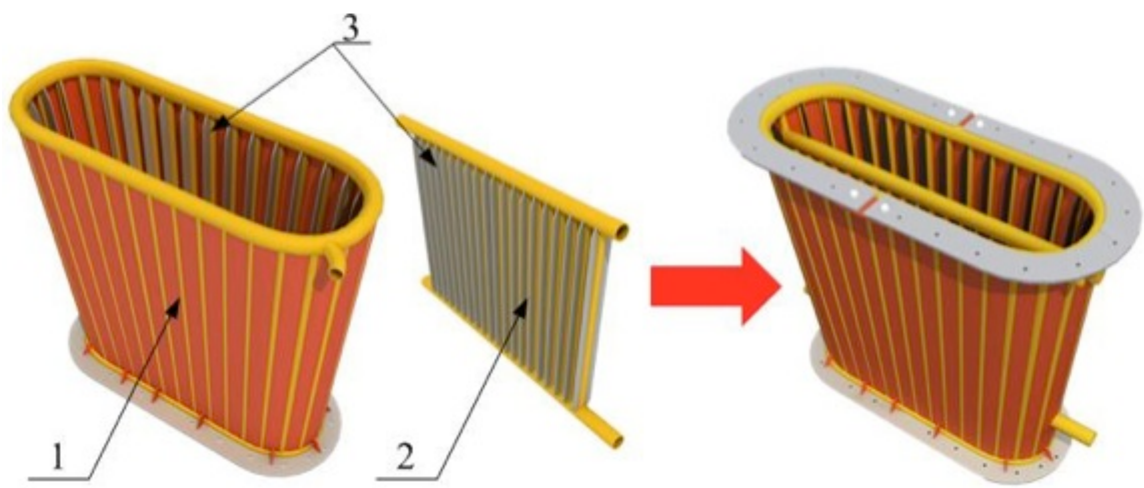


**Fig. (2).** Schematic of waste heat exchanger (1. outer heat exchanger, 2. inner heat exchanger, 3. fin).

exchanger outlet, which is used for measuring steam dryness and flow.

Measurement system: This system is composed of temperature sensor, pressure sensor and data acquisition instrument. Temperature sensor is used for measuring the temperature of calcined petroleum coke in heat exchanger, the temperature of water in the heat exchanger inlet, the temperature of steam in the heat exchanger outlet and so on. Pressure sensor is used for measuring the steam pressure and the water pressure. The data acquisition instrument is used for recording data. The temperature measuring points of calcined petroleum coke in heat exchanger are shown in Fig. (**3**).

The heat transfer coefficient of heat exchanger is calculated by the equation (1):

$$k = \frac{Q}{A \cdot \dfrac{\Delta t_{\max} - \Delta t_{\min}}{\ln \dfrac{\Delta t_{\max}}{\Delta t_{\min}}}} \tag{1}$$

where $k$ is heat transfer coefficient of heat exchanger, $W \cdot m^{-2} \cdot {}^{\circ}C^{-1}$; $A$ is the heat transfer area of the heat exchanger, $m^2$; $\Delta t_{max}$ is the maximum temperature difference of two heat

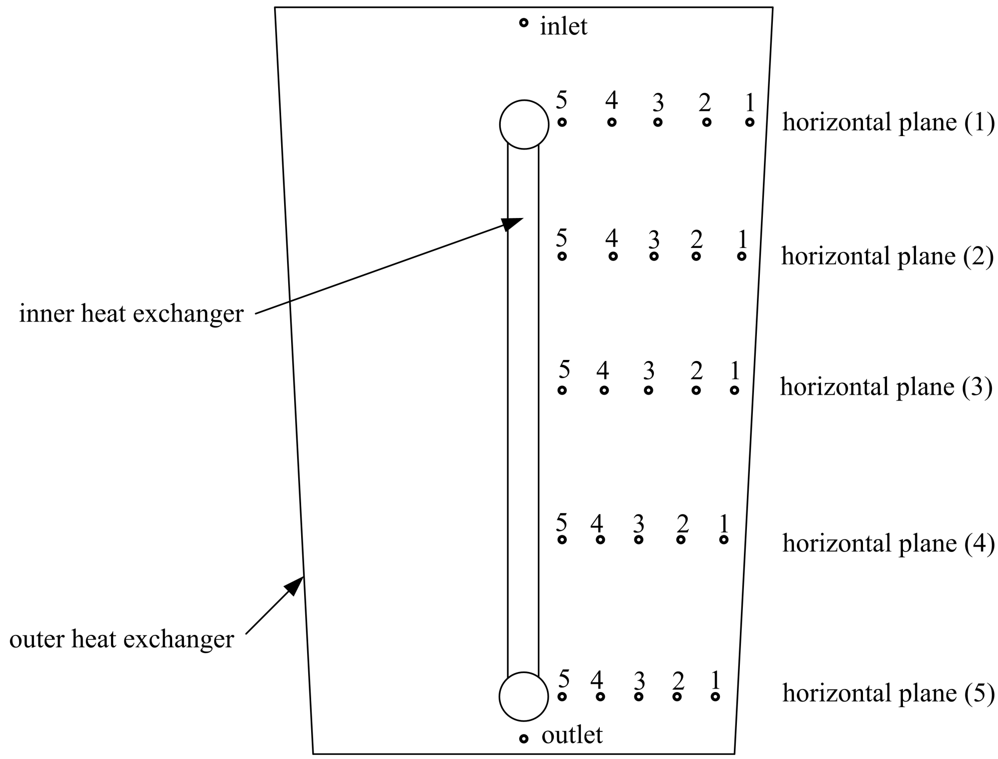


**Fig. (3).** The temperature measuring points of calcined petroleum coke in waste heat exchanger.

transfer medium, °C; $\Delta t_{min}$ is the minimum temperature difference of two heat transfer medium, °C.

The utilization ratio of waste heat is calculated by the equation (2):

$$\eta = \frac{q_1 \cdot (h_{out} - h_{in})}{c \cdot q_2 \cdot T} \times 100\% \tag{2}$$

where $\eta$ is the utilization ratio of waste heat, %; $q_1$ is water flow, kg·h$^{-1}$; $h_{out}$ is enthalpy value of heat transfer medium in the heat exchanger outlet, kJ·kg$^{-1}$; $h_{in}$ is enthalpy value of water in the heat exchanger inlet, kJ·kg$^{-1}$; $c$ is specific heat capacity, kJ·kg$^{-1}$·°C$^{-1}$; $q_2$ is calcined petroleum coke flow, kg·h$^{-1}$; $T$ is temperature of calcined petroleum coke when it gets into the heat exchanger, °C.

The nonuniformity coefficient of temperature is calculated by the equation (3):

$$\gamma = \frac{\Delta t_{\max}}{t_{\text{ave}}} \tag{3}$$

where $\gamma$ is nonuniformity coefficient of temperature; $t_{ave}$ is average temperature value of calcined petroleum coke in the horizontal plane, °C; $\Delta t_{max}$ is maximum temperature difference value of calcined petroleum coke in the horizontal plane, °C.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Effects of Calcined Petroleum Coke Velocity

The variations of the heat transfer coefficients with different calcined petroleum coke velocity are shown in Fig. (**4**). With the increase of calcined petroleum coke velocity, the heat transfer coefficient of inner heat exchanger and outer heat exchanger increase gradually. The gas film is the main influencing factor in lateral surface of heat exchange tube. With the increase of calcined petroleum coke velocity, the contact particle number of heat exchange tube lateral surface increases in unit time. The gas film is washed by calcined petroleum coke continually. The washing frequency increases. The higher the washing frequency, the thinner the gas film thickness, the smaller thermal resistance of the gas film. The heat transfer coefficient increases.

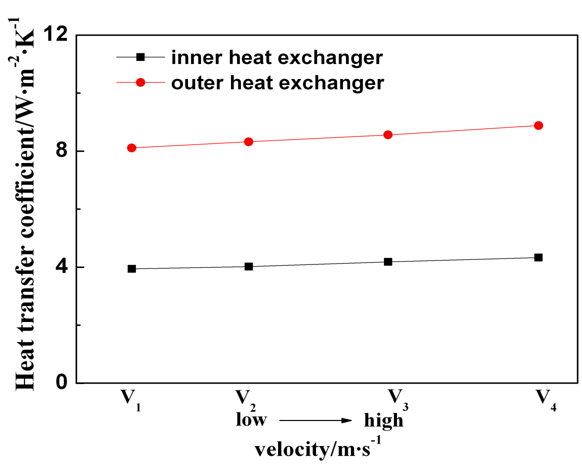


**Fig. (4).** Variations of heat transfer coefficient with different calcined petroleum coke velocity.

The variation of the waste heat utilization ratios with different calcined petroleum coke velocity are shown in

Fig. (**5**). When the velocity of calcined petroleum coke is small, the utilization ratio of waste heat increases gradually with the increase of calcined petroleum coke velocity. The reason is that with the increase of calcined petroleum coke velocity, the heat transfer coefficient of heat exchanger increases. The heat transfer quantity and utilization ratio of waste heat increase. When the velocity increases to a definite value, the utilization ratio of waste heat decreases gradually with the increase of calcined petroleum coke velocity. The reason is that with the increase of calcined petroleum coke velocity, the heat transfer coefficient of heat exchanger increases continuously, However; heat transfer time decreases. There is no guarantee that heat transfer processes; However, the utilization ratio of waste heat decreases.

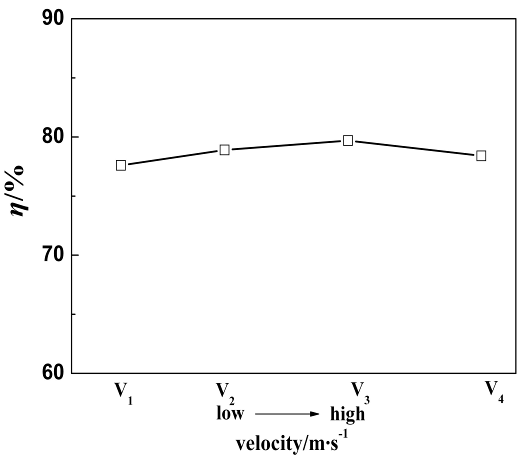


**Fig. (5).** Variations of waste heat utilization ratio with different calcined petroleum coke velocity.

## 3.2. Effects of Water Velocity in Waste Heat Exchanger Tube

The heat transfer coefficients with different water velocity in waste heat exchanger tube are shown in Fig. (**6**)

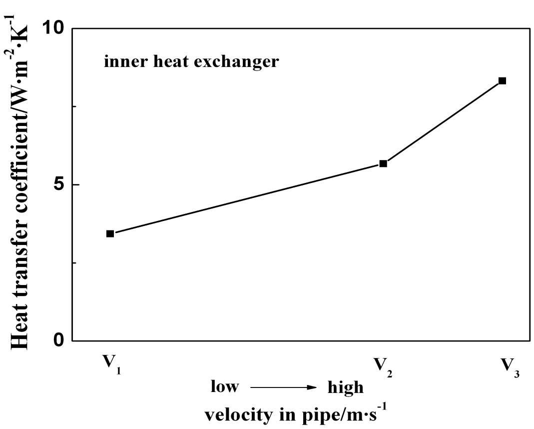


**Fig. (6).** Variations of heat transfer coefficient with different water velocity in inner waste heat exchanger tube.

and Fig. (**8**). The outlet water temperatures with different water velocity in waste heat exchanger tube are shown in Figs. (**7**, **9**). The water pressure is 0.4 MPa. The inlet water temperature is 40°C. With the increase of water velocity, the heat transfer coefficient of inner heat exchanger and outer heat exchanger increases gradually. The outlet water temperature decreases gradually. When the water velocity of waste heat exchanger tube is small, the outlet water phase is superheated steam. The outlet water temperature and dryness fraction are high. the thermal resistance in heat exchange tube is big. The heat transfer coefficient is small. With the increase of water velocity, the outlet water temperature and dryness fraction decrease. The outlet water phase is wet-steam. The thermal resistance in heat exchange tube decreases. The heat transfer coefficient increases. When the water velocity increases to a definite value, the outlet water phase is supercooled water. The outlet water temperature decreases and heat transfer coefficient increases.

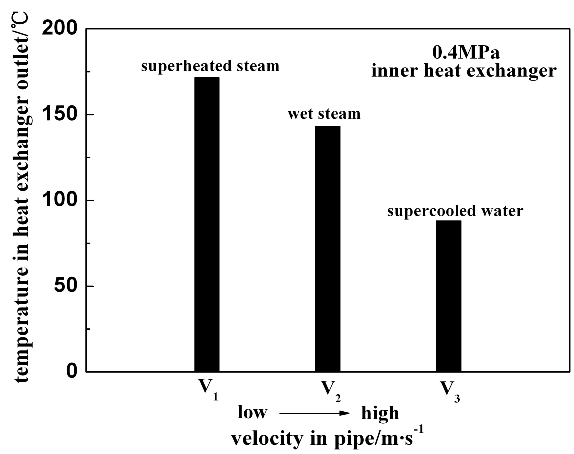


**Fig. (7).** Variations of the outlet water temperature with different water velocity in inner waste heat exchanger tube.

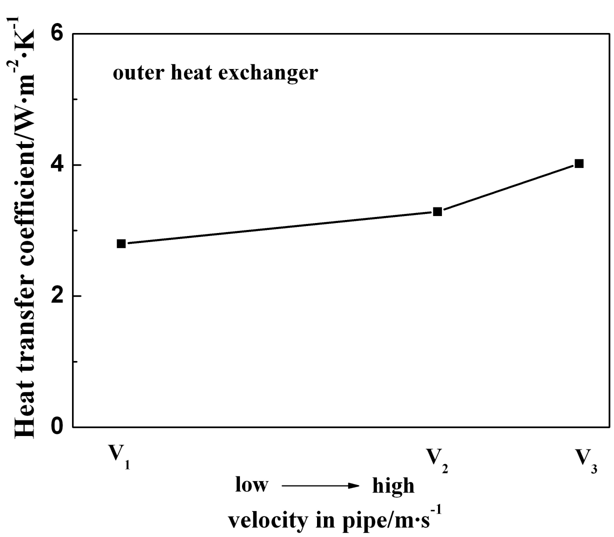


**Fig. (8).** Variations of heat transfer coefficient with different water velocity in outer waste heat exchanger tube.

**Table 1. Performance parameters contrast of fin-and-tube waste heat exchanger and light-and-tube waste heat exchanger.**

| Heat Exchanger Tube Type | Fin-and-Tube | Light-and-Tube |
|---|---|---|
| The average temperature of calcined petroleum coke in heat exchanger outlet | 181 °C | 195 °C |
| The nonuniformity coefficient of temperature in heat exchanger outlet | 0.0757 | 0.1123 |
| The average steam producing rate | 75.6 kg/h | 68.4 kg/h |
| The average utilization ratio of waste heat | 71.5 % | 78.9 % |

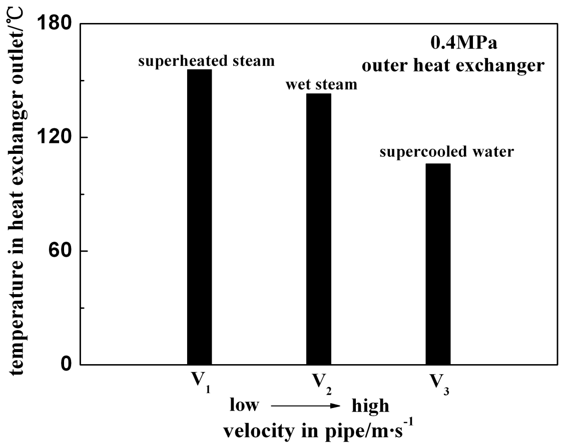


**Fig. (9).** Variations of the outlet water temperature with different water velocity in outer waste heat exchanger tube.

### 3.3. Effects of Fin-and-Tube

Performance parameters contrast of fin-and-tube waste heat exchanger and light-and-tube waste heat exchanger are shown in Table **1**. Compared with light-and-tube heat exchanger, the heat transfer performances of fin-and-tube heat exchanger increase. The average temperature of calcined petroleum coke in heat exchanger outlet decreases. The average temperature value reduce 14 °C. The uniformity degree of temperature in heat exchanger outlet increases. The nonuniformity coefficient of temperature reduces 32.6 %. The average steam producing rate rise 7.2 kg/h. The average utilization ratio of waste heat rises 7.4 %. The reason is that the heat conductivity coefficient of calcined petroleum coke is small. The thermal resistance of tube is big. When the axial fin is equipped with heat exchanger tube, the heat transfer area increases obviously. The heat transfer process is strengthened.

## CONCLUSION

The waste heat of calcined petroleum coke is utilized by fin-and-tube waste heat exchanger. With the increase of calcined petroleum coke velocity, the heat transfer coefficient of inner heat exchanger and outer heat exchanger increases gradually. The utilization ratio of waste heat increases first and then decreases, so this has an optimum calcined petroleum coke velocity. With the increase of water velocity, the heat transfer coefficient of inner heat exchanger and outer heat exchanger increases gradually. The outlet water temperature decreases gradually. Compared with the type of heat exchanger tube is light-and-tube, the heat transfer performances of fin-and-tube heat exchanger increase. The average steam producing rate rise 7.2 kg/h. The average utilization ratio of waste heat rises 7.4%. The average temperature of calcined petroleum coke in heat exchanger outlet decreases. The uniformity degree of temperature in heat exchanger outlet increases.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

## ACKNOWLEDGEMENTS

This work was financially supported by Shandong Provincial Natural Science Foundation, China (No. ZR2013EEQ005), Shandong Provincial Science and Technology Development Program, China (No. 2013GGX10404) and Weifang Science and Technology Development Program (No.20121148).

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Received: November 23, 2013 Revised: March 20, 2014 Accepted: March 20, 2014