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Research Paper

EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER CHARACTERISTICS OF HIGH PRESSURE GAS IN AN AUGMENTED HEAT EXCHANGER

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In Indian Coal mines, underground mines, mineral ore mines syngases at high pressure and high temperature are found in large quantities. This syngas is highly toxic, harmful and flammable gases which are present in atmosphere. It may cause many accidents. Hence it is necessary to reduce the content of syngas from mines in the atmosphere. This paper describes convective heat transfer characteristics of high pressure gas in mines. Heat transfer in convection cooling section of pressurized coal gasifier with the membrane helical coils and membrane serpentine tubes under high pressure is experimentally investigated. High pressure single gas (He or N_2) and their mixture (He + N_2)gas serve as the test media in the test pressure range from 2.5 Kg/cm^2 to 10 Kg/cm^2. The results shows that the convection heat transfer coefficient of high pressure gas is influenced by the working pressure, gas composition and symmetry of flow around the coil, of which the working pressure is the most significant factor. The average convection heat transfer coefficients for various gases in heat exchangers are systematically analyzed. The heat transfer coefficient of heat exchanger with membrane helical coils is greater than that of the membrane serpentine-tube heat exchanger under the same conditions. It is found that the heat transfer coefficient increment of the membrane helical-coil heat exchanger is greater than that of the membrane serpentine-tube heat exchanger with the increase of gas pressure and velocity.

Keywords: Membrane helical coil, High pressure gas, Convective heat transfer, Membrane serpentine tube

INTRODUCTION

Figure 1 shows a line diagram of mines exhaust gases. In mines the syngas are found in large quantity at high temperature and high pressure which caused many accidents. Some of the examples are Raniganj Blast, Jharia

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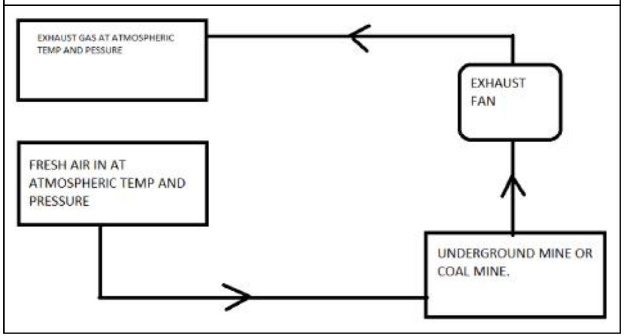
Figure 1: Line Diagram of Mines Exhaust Gases



Blast and Anjani Blast which caused many human lifes to death.

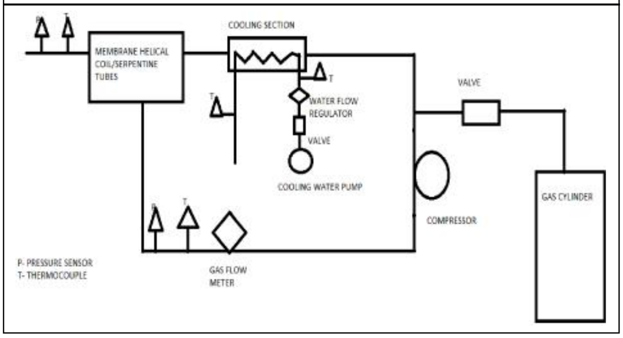
This accident happens frequently due to fact that available gas which is at high temperature and pressure is directly exhausted to the atmosphere through exhaust fans and fresh new air is sucked into the mines for respiration. Hence it is necessary not to throw this highly toxic, harmful and flammable gas in the surrounding environment.

This work is based on experimental investigation of this technology which will reduce the pressure and temperature of the harmful syngas.

EXPERIMENTAL SET UP AND PROCEDURE

A schematic of the experimental set up is shown in Figure 2. The system consists of the following components: test section, heat recovery section, cooling section, heater, compressor and other parts. To achieve high pressure, the whole experimental system is closed and airtight. The gas pressure is controlled by inflation from gas cylinder. The gas flow is maintained by a volumetric compressor. The counter-current flow is used in this system. The mass flow rate of the testing fluid is measured by flowmeters. The absolute pressure at the inlet of the test section is measured by a strain gauge absolute pressure transducer. The temperatures of the gas and water are measured with the calibrated copper-constantan thermocouples. During the experiments, the input electric power to the heater is controlled by a voltage regulator. Depending on the heating power, a steady state condition is achieved after 3-5 hour approximately. The steady state condition is considered to be achieved when the maximum variation of 0.5 °C for each thermocouple within 20 min. When the steady state condition is established, the gas and water temperatures, input power, ambient temperature and the mass flow rate are recorded. The test conditions for each gas are from 2.5 Kg/cm^2 to 10 Kg/cm^2.

Figure 2: Line Diagram of Experimental Set Up



Four thermocouples are placed all over the setup which gives the inlet temperature of gas (T_1), outlet temperature of the gas (T_2), inlet temperature of the water (T_{w1}), outlet temperature of hot water (T_{w2}), respectively. From the gas cylinder the gas is pass to the compressor for compression at high pressure and temperature. When the high pressure and temperature of the syngas is passing from the rotary compressor to the heat exchanger with membrane helical coil pitch of 20 mm at that time initial pressure and temperature is recorded. At the same time initial water tank temperature is also recorded. After compression the high pressure and temperature syngases is passing from the heat exchanger with membrane helical coil pitch of 20 mm. From the cooling section the water are falling on the heat exchanger for cooling purpose. When the steady state condition is established, gas and water temperatures, input power, ambient temperature and mass flow rate are recorded. The pressure of the hot gas at entry to the rotary compressor is controlled by opening the regulatory valve. Thus for different pressure of gas we have different readings. Now the heat exchanger with membrane helical coil pitch of 20 mm is removed from the set up and heat exchanger with membrane serpentine tubes is placed. Again the same procedure is continued for the heat exchanger with membrane helical coil pitch of 16 mm as above to note minimum of six readings.

RESULTS AND DISCUSSION

Table 1 shows Performance Parameter of Heat exchanger with membrane helical coil pitch of 20 mm, it is found that the log mean temperature of N_2+He gas is higher than other two gases and convective heat transfer coefficient of helium gas (He) is higher than the other nitrogen gas (N_2) and N_2+He gas. This happens due to the fact that the kinetic viscosity of helium gas (He) is higher than that of nitrogen gas (N_2), which can cause the lower Reynolds number of helium gas compared with nitrogen at same condition. However, the thermal conductivity of helium gas is much larger than that of nitrogen gas. In the end, the convective heat transfer coefficients of helium gas (He) are greater than that of nitrogen gas (N_2) and mixture gas (N_2+He) gas at the same pressure and temperature.

Table 2 shows Performance Parameter of Heat exchanger with membrane serpentine tube, it is found that the log mean temperature of N_2+He gas is higher than other two gases and overall heat transfer coefficient of He gas is higher than the other N_2 and N_2+He gas. The convection heat transfer coefficient of He gas is higher than the N_2 and N_2+He gas. At the same pressure and temperature, the heat transfer coefficient of helium gas is greater than those of nitrogen gas. Since heat transfer coefficients are related to thermal conductivity, the heat transfer increases with the increase of thermal conductivity for nitrogen gas, helium gas and mixture gas (N_2+He).

Table 1: Performance Parameter of Heat Exchanger with Membrane Helical Coil Pitch of 20 mm

S. No.	Results	N_2 Gas	He Gas	N_2+He Gas
1.	Log. Mean Temp. Difference (LMTD) (°C)	57.5829	54.0297	65.0894
2.	Overall Heat Transfer Coefficient (W/m^2K)	$46.3818*10^3$	$46.82937*10^3$	$46.5981*10^3$
3.	Convection Heat Transfer Coefficient (W/m^2K)	0.012506	0.012580	0.011776
4.	Actual Heat Transfer (W)	6304.4911	$31.456*10^3$	$18.947*10^3$
5.	Maximum Possible Heat Transfer (W)	$28.619*10^3$	$28.208*10^3$	$28.941*10^3$
6.	Effectiveness of Heat Exchanger	0.22028	0.97517	0.65466

Table 2: Performance Parameter of Heat Exchanger with Membrane Serpentine Tube

S. No.	Results	N_2 Gas	He Gas	N_2+He Gas
1.	Log. Mean Temp. Difference (LMTD) (°C)	59.4029	56.7178	67.6122
2.	Overall Heat Transfer Coefficient (W/m^{2}K)	46.0673*10^3	47.4441*10^3	47.0629*10^3
3.	Convection Heat Transfer Coefficient (W/m^{2}K)	0.011949	0.012493	0.012055
4.	Actual Heat Transfer (W)	6.231*10^3	31.050*10^3	18.757*10^3
5.	Maximum Possible Heat Transfer (W)	29.499*10^3	28.097*10^3	28.892*10^3
6.	Effectiveness of Heat Exchanger	0.21122	0.96511	0.64920

Table 3 shows Performance Parameter of Heat exchanger with membrane helical coil pitch of 16 mm, it is found that the log mean temperature of N_2+He gas are highest than other two gases and convection heat transfer coefficient of He gas is higher than the other N_2 and N_2+He gas. The convection heat transfer coefficients increase with the reduction of the radial pitch for nitrogen, helium, and mixture gas (N_2+He). In the case of constant flow rate, the small radial pitch means small cross section and high gas velocity, which can cause the high heat transfer coefficient. In addition, the turbulent intensity of syngas flow across membrane helical coils increases with the decrease of radial pitch to cause the increase of the local heat transfer coefficients on membrane helically coiled tube surface.

Table 3: Performance Parameter of Heat Exchanger with Membrane Helical Coil Pitch of 16 mm

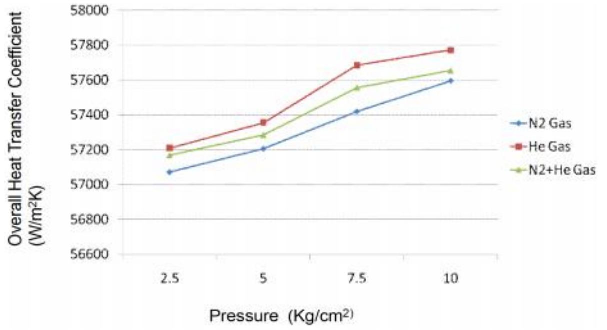
S. No.	Results	N_2 Gas	He Gas	N_2+He Gas
1.	Log. Mean Temp. Difference (LMTD) (°C)	58.1926	58.6774	69.2652
2.	Overall Heat Transfer Coefficient (W/m^{2}K)	45.781*10^3	47.4839*10^3	45.4752*10^3
3.	Convection Heat Transfer Coefficient (W/m^{2}K)	0.012344	0.012620	0.0120583
4.	Actual Heat Transfer (W)	6393.24	31.248*10^3	19.418*10^3
5.	Maximum Possible Heat Transfer (W)	28.821*10^3	28.308*10^3	29.124*10^3
6.	Effectiveness of Heat Exchanger	0.22183	0.98384	0.66671

HEAT TRANSFER CHARACTERISTICS

Membrane Helical Coil Pitch of 20 mm

Figure 3 shows the plot between overall heat transfer coefficient and pressure for different gases of membrane helical coil pitch of 20 mm. The heat transfer coefficients at different pressure of three different gases for helical coil pitch of 20 mm at same inlet

Figure 3: Overall Heat Transfer Coefficient vs Pressure

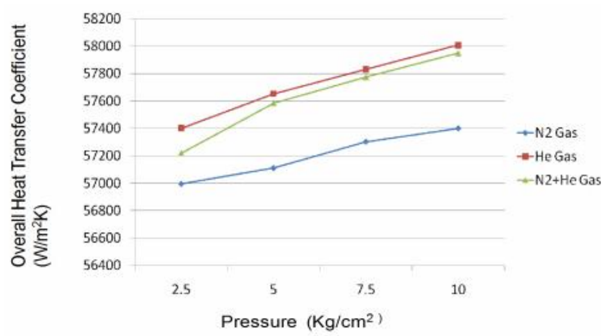


temperature and volume flow. It is found that, at the same temperature, the average heat transfer coefficient increases linearly with the increase of pressure for all gases.

Membrane Serpentine Tube

Figure 4 shows the plot between overall heat transfer coefficient and pressure for different gases of membrane serpentine tube. The heat transfer coefficients increases with the increases of the pressure it is found that for all gases. The heat transfer coefficients of various gases at the same pressure and temperature are different. It is observed that the heat transfer coefficients of Helium gas is greater than of Nitrogen gas and the heat transfer coefficients of the gas mixture lies in between Nitrogen and Helium gas.

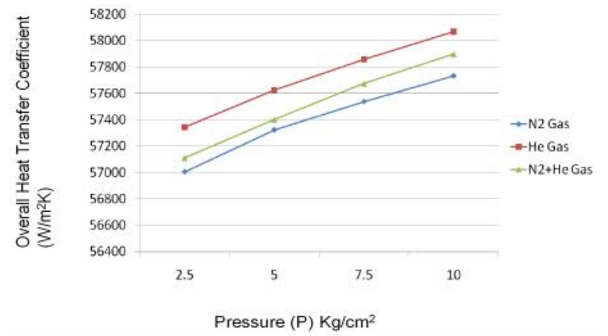
Figure 4: Overall Heat Transfer Coefficient vs Pressure



Membrane Helical Coil Pitch of 16 mm

Figure 5 shows the plot between overall heat transfer coefficient and pressure for different gases of membrane helical coil pitch of 16 mm. The average heat transfer coefficient increases linearly with the increase of pressure for all gases. This is due to the increases of pressure leads to the change of the fluid physical properties. At the same pressure and the temperature, the heat transfer coefficient of Helium gas is greater than of Nitrogen gas and the heat transfer coefficient of the gas mixture lies in between Nitrogen and Helium gas.

Figure 5: Overall Heat Transfer Coefficient vs Pressure



CONCLUSION

Experimentation was carried out using membrane helical coil pitch of 20 mm, membrane serpentine tube and membrane helical coil pitch of 16 mm. It is found that membrane helical coil pitch of 16 mm profile heat exchangers are more effective in transferring the heat over the membrane serpentine tube and membrane helical coil pitch of 20 mm profile heat exchanger. The logarithmic mean temperature difference obtained for membrane helical coil pitch of 16 mm heat exchanger is more than the serpentine tube heat exchanger and membrane helical coil pitch of 20 mm heat exchanger. Thus, for the same mass flow rate of gas and water more heat transfer is obtained in membrane helical coil pitch of 16 mm profile heat exchanger. From the analysis for both types of heat exchangers, it is clear that heat exchanger effectiveness and overall heat transfer coefficients is more for membrane helical coil pitch of 16 mm profile heat exchanger over the membrane serpentine tube and membrane helical coil pitch of 20 mm profile heat exchanger. Hence, it is suggested to reduce the high temperature and high pressure of the syngases from the mines with the help of a heat exchanger with membrane helical coil and heat exchanger with membrane serpentine tube.

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