Chapter 6

Conclusion and Scope for Future Work

6.1 Conclusion

In the present thesis, an experimental facility was developed to study the particle emission behavior of combustible materials. This facility can attain a maximum furnace temperature of 1350 °C with a maximum air flow rate of 25 $Lmin^{-1}$. The aerosol characteristics of a nuclear grade bare and alumina coated graphite at high temperature conditions were studied. Concentration of CO_2, CO and particles generated during the burning were measured and interpreted for different temperatures and flow rates.

I. Experiments were conducted to study the effect of isokinetic and anisokinetic sampling for aerosol particles in the laminar flow regime in a tube. Isokinetic, sub isokinetic and super isokinetic condition were tested, and the findings show that sampling of aerosol does not depend on flow rates used in this work (10 - 25 $Lmin^{-1}$) and the diameter of sampling nozzle for Stokes number less than 0.01 and $0.2 < \frac{U_0}{U} < 5.0$.

II. For accurate measurement of aerosol, transport losses due to diffusion, thermophoresis and gravitational settling were calculated using empirical correlations and found to be less than 5%. Effects of condensation on the measurement of particle concentration and size distribution were calculated, and found to be negligible.

III. In case of graphite heating at constant temperatures (500, 600, 700, 800 and 900 °C), the burning of graphite was observed as the temperature exceeded 500 °C. At 600 °C, the number concentration was seen to be rising rapidly at initial times but decreased slowly afterwards. The peak number concentration measured for this case was 1.4×10^6 #/cm^3 when the air flow rate was 25 $Lmin^{-1}$. Similar nature of behavior was observed for the number concentration profile at 700 °C. For this case, the peak number concentration was found to be highest at 5.3 $\times 10^6$ #/cm^3 among the tested temperatures. After 700 °C, the peak number concentration was found to decrease at higher temperatures. The highest concentration of CO gas was obtained for combustion at 700 °C and its value was 0.04 v/v%.

IV. When graphite was burnt at different heating (2, 4, 6 and 8 °C/min) and flow rates (10, 15, 20 and 25 Lmin^{-1}), the highest concentration of particulate matter and CO gas was obtained for lower temperatures in the range of 600 - 800 °C due to incomplete combustion. The maximum concentration of particles and CO was 5.13 × 10^6 #/cm^3 and 0.16 v/v% respectively. Withrise in temperature, the concentration of CO and particulate matter was observed to decrease, while the CO_2 production increased. The CO_2 production reached a maximum value and remained constant thereafter, indicating saturation of the oxidation process.

V. Particle generation increased with increase in heating rate and decrease in air flow rate while it decreased at low heating rate and high air flow rate. The peaks for the particle, CO and CO_2 generation shifted laterally at higher temperature with increasing heating rate due to thermal soaking effects. In addition, it was found that at lower heating rates and higher flow rates, the loss in graphite weight during burning was maximum.

VI. For the case of coated samples, the graphite surface was protected against oxidation till 700 °C. At higher temperatures (800 and 900 °C), surface degradation starts and the diffusion of oxygen and oxidation rate increases. The peak number concentration was found to be 5.4 × 10^5 #/cm^3 at 900 °C. It was observed that the generation of particles from the coated graphite surface occurred only for approximately 20 minutes of continuous heating after which the number concentration decreased back to the background levels. For each test temperature, the number concentration of coated sample was found to less than that for the bare sample. Overall, it was seen that the structure of graphite remained largely intact at high temperatures as an effect of coating. A significant reduction in aerosol formation and CO emission was also noticed for coated samples.

VII. For the bare sample, the aerosol generation at 25 $Lmin^{-1}$ begins at a temperature of 600 °C while for the coated sample, this phenomenon starts at 800 °C. Moreover, the particle concentration for the coated sample was lesser than for the bare sample under these conditions. This signify that the incomplete combustion was lesser for the case of coated samples even when the burning occurred at 200 °C higher temperature than the bare graphite samples.

VIII. Evaporation-condensation and transport of unburnt graphite particles could be linked to the generation of particles in nucleation and accumulation mode size ranges, respectively. The surface disintegration and air erosion was also related to the transport of particles formed at the burned surface. This study found that the transition of graphite oxidation reaction framework from progressive to shrinking core model takes place around 700 °C. The flaky surface characteristics of graphite block also disappear and fused-type surface characteristic come into existence at this temperature.

6.2 Scope for future work

- In the present work, smaller size particle formation was attributed to the vaporization/condensation process. It means that certain chemical products get vaporized as their temperature increases above their boiling point and get condensed below this temperature. Therefore, it is felt that for defining a more detailed mechanism of particle formation, the chemical characterization of generated particle during experiment is needed.

- In the present work, thickness of alumina coating was about 100 microns. For knowing the effects of coating thickness on aerosol generation and its characterization, experiment need to be conducted by varying the thickness of alumina coating.
- The present work addresses coating subjected to a maximum temperature of 900 °C. More research at higher temperatures is needed to explore the utility of coatings at elevated temperatures.
- Other than Alumina, other coating materials need to be studied for generating more information on this subject
- CFD simulation for validating experimental results would require the use of combustion, kinetics, surface erosion, nucleation and growth of aerosol.

Summary

The present chapter, discussed the overall conclusion of behavior of bare and Al_2O_3 coated graphite specimens in terms of particle generation at high temperatures (500-900 °C). For bare graphite specimen, particle formation started at 600 °C. Concentration of emitted CO gas and the particles was observed to be maximum at 700 °C, decreasing thereafter. Both of these are the products of incomplete combustion indicating that the intensity of oxidation is highest at this temperature. The size distribution of the emitted particles was observed to be bimodal consisting of major fractions in 10-50 nm and 100-200 nm size ranges. For coated specimens, graphite surface was protected against oxidation till 700 °C. At higher temperatures (800 °C and 900 °C), surface degradation initiates increasing the rate of oxygen diffusion. However, the rate was found to be slower as compared to the case of bare graphite. Transition temperature for the case of coated graphite was found to be higher than that for bare graphite. In contrast to the emissions from bare graphite specimens, particle formation was found to be temporarily sporadic.