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Development of Aerosol Measurement, Sampling and Generation Experimental Facilities under High Temperature and High Pressure

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1. INTRODUCTION

The measurement of aerosols associated with the HVAC system, filter, automobile exhaust gas, air quality, accuracy or calibration of aerosol instrument including overall environment industry is necessary for the assessment of the aerosols.

Past aerosol experiments have been performed in ambient condition, high temperature/low pressure or high pressure/low temperature. In this paper, aerosol measurement, sampling and generation experimental facilities concerning the investigation of aerosol dynamic under high temperature (up to operating temperature of 170℃) and high pressure (up to operating pressure of 8 bar(a)) has been designed.

Temperature affects not only the material properties of the carrier gas/aerosols such as diffusivity but also aerosol deposition rates. The wall temperature also determines the rates of steam condensation and it plays an essential role for aerosol removal. For a given aerosol release, the impact of formation and growth and concentration of aerosols depends on pressure. The pressure is key factor determining Knudsen number and it affects aerosol dynamics. Hence, it is important to design experimental facilities to simulate the aerosols transport phenomena and removal mechanisms in the high temperature and high pressure (HT/HP) [1].

In case of Nuclear Power Plant, during the Light Water Reactor (LWR) severe accident, core degradation results in the release of both vapors and aerosol particles which differ in composition depending on their source terms.

Vapor and aerosols generated under severe accident enter the containment atmosphere and are distributed in the containment by atmospheric flow. Temperature and pressure in the containment increase until containment spray system, fan cooler system or FCVS initiates to extract heat and avoid pressurization. For that reasons, the formed fission product aerosols undergo HT/HP, aerosol experimental facilities need to be developed to perform aerosol generation, mixing, sampling and measurement under this thermal-hydraulic conditions.

The main purpose of the experimental facility is to develop not only multi-purpose test loops applying for aerosol industry but also to evaluation performance of engineered safety system including containment filtered venting system.

The main experiment will be carried out in this loop and provide representative behavior of the aerosols under HT/HP conditions.

2. DESCRIPTION OF TEST LOOP

The test loop has four key components, which are the aerosol generation, mixing, sampling and measurement system. Figure 1 shows a flow diagram of experimental loop and thermal-hydraulic specifications applied at these experiments are indicated in Table 1.

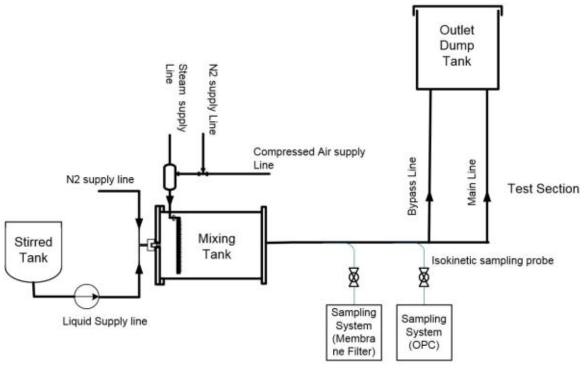

Fig.1: The Flow Diagram of Experimental loop

Table 1: Specification of thermal-hydraulic of Test Loop

Variable	Value
Steam Mass Flow Rate	≤ 1000 kg/hour
Compressed Air Flow Rate	≤ 600 m^3/hour
Nitrogen Gas Flow Rate	≤ 100 m^3/hour
Max. Operating Pressure	8 bar(a)
Max. Operating Temperature	170℃

2.1 Aerosol Generation System

The aerosol generation system, which shown in Figure 2, is connected to the aerosol mixing system and provide aerosol species used in these experiments. Silicon dioxide (SiO_2), also known as Silica, is used for representative aerosol species not only because of reproducibility of target size but also its insoluble characteristic. SiO_2 prepared by Sol-gel polymerization method has monodisperse solid particles having uniform size distribution. SiO_2 is mixed with ethanol in the stirred tank, where recirculation continues until injection starts. A mixture of ethanol and SiO_2 pumps into the two-fluid nozzle at the same time as nitrogen or air injects. In the two-fluid nozzle, the aerosol is generated with specific spray patterns, such as a circular or cone, in which a liquid with the aerosol is mixed with a feeding gas. In general, two-fluid nozzle is used to generate fine droplet and to enable complete evaporation of the ethanol from the droplet. It allows for use of different aerosol material and constant aerosol concentration. The aerosol concentration is easy to control by adjusting the liquid flow rate and aerosol mass fraction in the ethanol. A two-fluid nozzle with external mixing (Spraying System Co., Liquid cap 2850 and Air cap 60) is used for the generation of high concentration insoluble aerosol particles. The fluid and air cap can be replaced to increase or decrease the flow rate. For feeding aerosol mixture, gear pump is used for dosing the aerosol at high pressure.

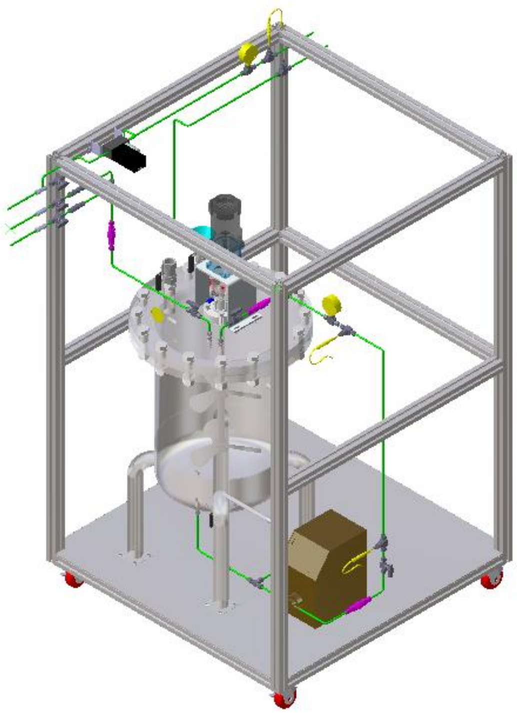

Fig.2: The Aerosol Generation System

2.2 Aerosol Mixing System

The two-fluid nozzle requires fluid source and gas source at the same time. Fluid and air stream are mixed outside of the two-fluid nozzle. The mixture spray of ethanol and SiO_2 from the two-fluid nozzle is injected into a mixing tank with a single gas source. Clean-out needle equips to eliminate clogging and ensure spray stability. Each gas source line has regulators to adjust pressure which can be affect atomizing droplet size, maximum spray distance and spray angle.

The main purpose of the mixing tank is to provide not only sufficient time to evaporate the ethanol but also mixing with the main carrier gas. The mixing tank is a 1.1 m width, 0.5 m in diameter cylindrical vessel and shown in Figure 3. Main carrier gas of nitrogen, dry air and steam pass through circular nozzle with 79 holes inside the mixing tank. Main carrier gas and mixing tank are heated to evaporate the droplets of the feed ethanol from the two-fluid nozzle. Dry aerosols formed in the mixing tank are feed into the test section which connected to the aerosol sampling system.

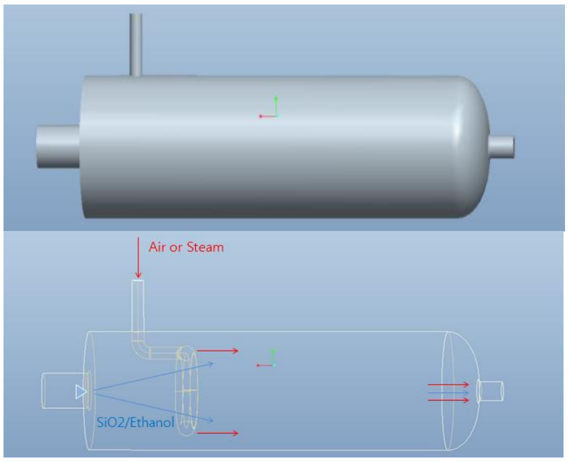

Fig.3: The Aerosol Mixing System

2.3 Aerosol Sampling/Measurement System

The purpose of aerosol sampling system is to ensure that a representative sample of aerosol enters the sampling prove when sampling is taken from the test section under HT/HP conditions. The sampling probe is aligned to parallel to the aerosol stream and the sampling velocity entering the sampling probe is designed to control to equal the free-stream velocity in the upstream of the probe inlet.

Under the isokinetic sampling probe, it maintains same concentration and distribution of aerosol between the free-gas stream and the sampling gas. To control the approaching velocity and have constant velocity, mass flow controller (MFC), critical orifice and vacuum pump are used according to the type of main carrier gas. MFC can be used in case that air or nitrogen is used for the main carrier gas and vacuum pump can be used to provide assistant to MFC. MFC is used to control the sampling gas flow and to determine the sampled volume. If steam is used for the main carrier gas, calibrated critical orifice can be used to produce a target mass flow rate and condensed steam also be measured by condensation tank in the system.

The filter holders have been designed to be applied at HT/HP conditions and it provides direct measurement of mass concentration. The filter holder has a conical flow path to minimize deposit losses in the holder inlet including perforated support plate for the filter and O-ring for sealing. It is designed for a commercial filter size of 47mm and any types of filter, such as glass fiber membrane filter, capillary pore membrane filter and ceramic membrane filter etc.

Optical Particle Counter (OPC), GRIMM 1.109, detected by scattering of white light is used for real-time measurement of distribution of aerosol mass concentration and number concentration. The lower detection range is approximately from 0.25 to 32 ㎛ with a sample flow of 1.2 LPM.

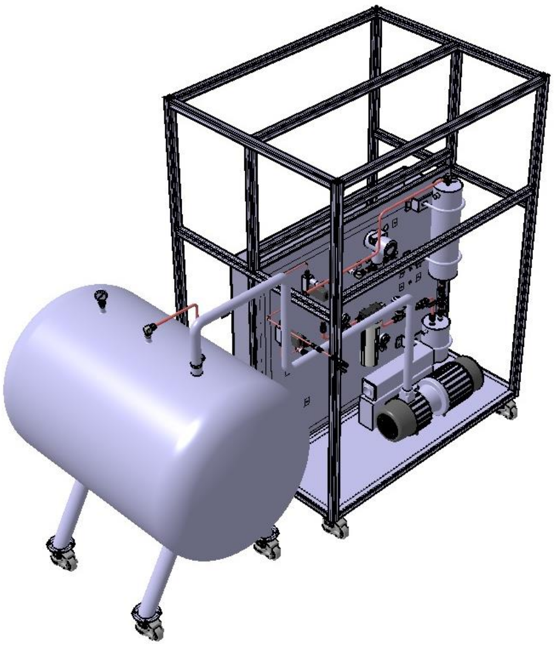

Fig.4: The Aerosol Sampling System

3. CONCLUSIONS

FNC Technology Co., Ltd. recently developed the multi-purpose aerosol control systems including aerosol generation, mixing and sampling and also built the experimental facilities to test the performance of those systems. The aim of the research is to be able to 1) develop the aerosol generation, mixing, sampling and measurement system and conduct tests based on various aerosol concentration, thermal-hydraulic conditions including high temperature and pressure and type of carrier gases (air, nitrogen and steam), applicable to the thermal power plant, environmental industry, automobile exhaust gas, chemical plant, HVAC system including nuclear power plant, and 2) investigate aerosol behaviors and removal mechanisms under these conditions. The tests with the main carrier gas of air will be performed on PHASE Ⅰ, steam will be conducted on PHASE Ⅱ.

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