CHAPTER 2

EXPERIMENTAL APPARATUS AND PROCEDURES

The experimental apparatus and procedures used in the present study to unravel the characteristics of the mixed convective vortex flow resulting from a low speed gas jet impinging onto a heated rotating disk confined in a vertical cylindrical chamber are modified slightly from those established in our previous study [13].

2.1 Experimental Apparatus

A schematic of the experimental system is shown in Fig. 2.1. The test section schematically shown in Fig. 2.2 includes a circular rotating disk held horizontally in a vertical cylindrical chamber with the gas injected vertically downward through a long straight vertical pipe into the chamber. Note that for clear illustration the plots in Fig. 2.1 and 2.2 are not proportional to the actual dimensions of the apparatus. In the present experiment study, we adopted air as the working fluid intending to save cost of the experiment. The present experimental system consists of five parts: (1) heating unit, (2) gas injection unit, (3) cylindrical chamber, (4) rotating disk unit and (5) flow visualization unit. They are described briefly in the following.

(1) Heating unit: The heating unit is designed to maintain the circular disk at the preset uniform temperature during the experiment. It is composed of a 10.0-mm thick copper plate of eight-inch in diameter, acting as the rotating disk, placed above another 20.0-mm thick stationary copper plate of the same diameter, which is heated by D.C. power supplies. The lower stationary copper plate is then placed on a bakelite plate. A gap height of 1 mm is kept between the two copper plates allowing the thermal radiation and convection to transfer heat from the lower to upper plates. The heater attached onto the back side of the lower stationary copper plate is divided into

3 concentric zones (Fig. 2.3). Each zone is independently heated by a power supply with the D.C. current passing through the nickel coil placed on the stainless steel holder. The entire heating unit is then placed on a Teflon plate. Additionally, to reduce the significant energy loss from the sidewall of the copper plates and Teflon plate, the lateral surface of the entire heating unit is wrapped with a 16.0-mm thick thermal insulation layer of superlon. A proper control of the voltage transferred from the power supplies to the heating coils leads to a nearly uniform disk temperature with a maximum deviation of 0.1℃ across the disk. Moreover, by using a slip ring the temperature of the rotating copper plate is measured by several corrected and calibrated T-type thermocouples at selected points located at 1-mm below the upper surface of the copper plate, which are fixed at the detection points through the small holes drilled from the backside of the plate. The locations of the detection points are indicated in Fig. 2.4.

(2) Gas injection unit: The gas injection unit consists of a 2 HP (Horse Power) air compressor, a flow meter, a smoke generator, filters, pressure regulator, and connection and injection pipes. In the experiments, the air is drawn from the ambient by the compressor and sent into a 300-liter and 100-psi high-pressure air tank and is filtered to remove moisture and tiny particles. The installation of the high-pressure air tank intends to suppress the fluctuation of the air flow and extends the life of the compressor. Then, the air is mixed with smoke tracers in the smoke generator and regulated by the pressure regulator and is later injected into the processing chamber through the injection pipe which is coaxial with the processing chamber. The downward vertical air jet issuing from the injection pipe exit impinges directly onto the heated rotating copper plate. In the present study, two injection pipes with diameters 10.0 and 22.1 mm are tested. The injection pipes are thermally well insulated by a superlon insulation layer of 16.0-mm thick to prevent heat loss from the compressed air. The distance between the exit of the injection pipe and the upper surface of the heated rotating disk is fixed at 20.0 mm. The gas temperature at the cross section 600.0 mm upstream of the injection pipe exit is measured by a calibrated T-type thermocouple. The measured value is considered as the temperature of the air injected into the processing chamber in view of the good thermal insulation over the pipe.

(3) Cylindrical chamber: The cylindrical chamber, which is made of 6.0-mm thick quartz glass to allow for the observation of the vortex flow pattern in the chamber, has a diameter of 291.0 mm. The distance between the chamber top and bottom is 200.0 mm. To facilitate the flow visualization, the chamber top is made of an acrylic plate. Air is injected vertically downward from the long straight circular injection pipe into the chamber and impinges directly onto the heated rotating disk. The air flows first over the heated rotating disk, then moves through the annular section of the chamber, and finally leaves the chamber via twenty circular outlets of 12.7 mm in diameter opened at the bottom of chamber. The chamber is sealed to prevent any gas leakage. The top, bottom and side walls of the chamber are thermally well insulated to reduce the heat loss from the processing chamber to the ambient during the experiment. More specifically, the entire chamber is insulated with a superlon insulator of 10.0 mm thick. The insulator can be opened during the flow visualization experiment.

(4) Rotating disk unit: The rotating disk assembly is designed to maintain the circular disk at the preset rotation speed during the experiment. It is comprised of a 10.0-mm thick copper plate of eight-inch in diameter, acting as the rotating disk, a direct-current electric motor, a pulley mechanism, a belt transmission, and a slip ring mechanism. The pulley mechanism connects the belt transmission with the direct-current motor. The heated rotating disk is connected to the upper end of a vertical shaft and is driven by the direct-current motor through the belt transmission. The rotation speed of the disk is adjusted by a controller and is continuously monitored by a tachometer.

(5) Visualization unit: A smoke-tracer flow visualization technique is employed to observe the flow patterns induced by the jet impinging onto the heated rotating disk in the cylindrical chamber. The smoke is produced from burning incense prepared from sandalwood. The smoke is mixed uniformly in the smoke generator and is carried out by the inlet air and is sent into the cylindrical chamber. The gas flow pattern in the chamber is illuminated by the vertical and horizontal plane light sheets produced by passing parallel lights from an overhead projector through two adjustable knife edges. The experimental system is located in a darkroom to improve the contrast of the flow visualization. The time variations of the flow pattern during the experimental processes from the top and side views are recorded by the Sony digital video camera DCR-PC100.

(6) Temperature measurement: To understand thermal characteristics of the steady and unsteady vortex flow, the temperature of the air flow in the processing chamber is measured by inserting a calibrated and corrected thermocouple probe into the chamber through twenty-four holes of 1.0 mm in diameter opened at the selected locations on the top of the chamber. In the experiment, the thermocouple tip is positioned at selected vertical distances from the upper surface of the disk. More specifically, the thermocouple probe is an OMEGA (model HYPO) mini hypodermic extremely small T-type thermocouple implanted in a 1.0 inch long stainless steel hypodermic needle.

2.2 Experimental Procedures

The experimental parameters included in the present study are the diameter of the injection pipe, jet-to-disk temperature difference, jet flow rate and disk rotation speed. Two injection pipes with D_j= 10.0 and 22.1 mm are to be tested. The jet-to-disk separation distance is fixed at 20.0 mm. The temperature difference and jet flow rate are respectively varied from 0 to 25℃ and 0 to 12.0 slpm (standard liter per minute). The disk rotation speed is varied from 0 to 50 rpm.

For each case the experiment starts with the air at the ambient temperature T_a compressed first into a smoke generator through the connection pipes, and then injected into the cylindrical chamber. Note that after the impinging jet flow in the chamber reaches steady or statistically stable state, we begin to rotate the disk during the experiment. The air moves over the heated rotating disk and finally leaves the processing chamber through the twenty circular outlets at the bottom of the chamber. In the meantime the disk rotation speed and the temperature of the disk are controlled at the preset levels. The temporal changes of the vortex flow patterns in the processing chamber are then photographed by the Sony digital video camera DCR-PC100 for various injection pipes, gas flow rates, disk rotation speeds and temperature differences between the disk and inlet gas.

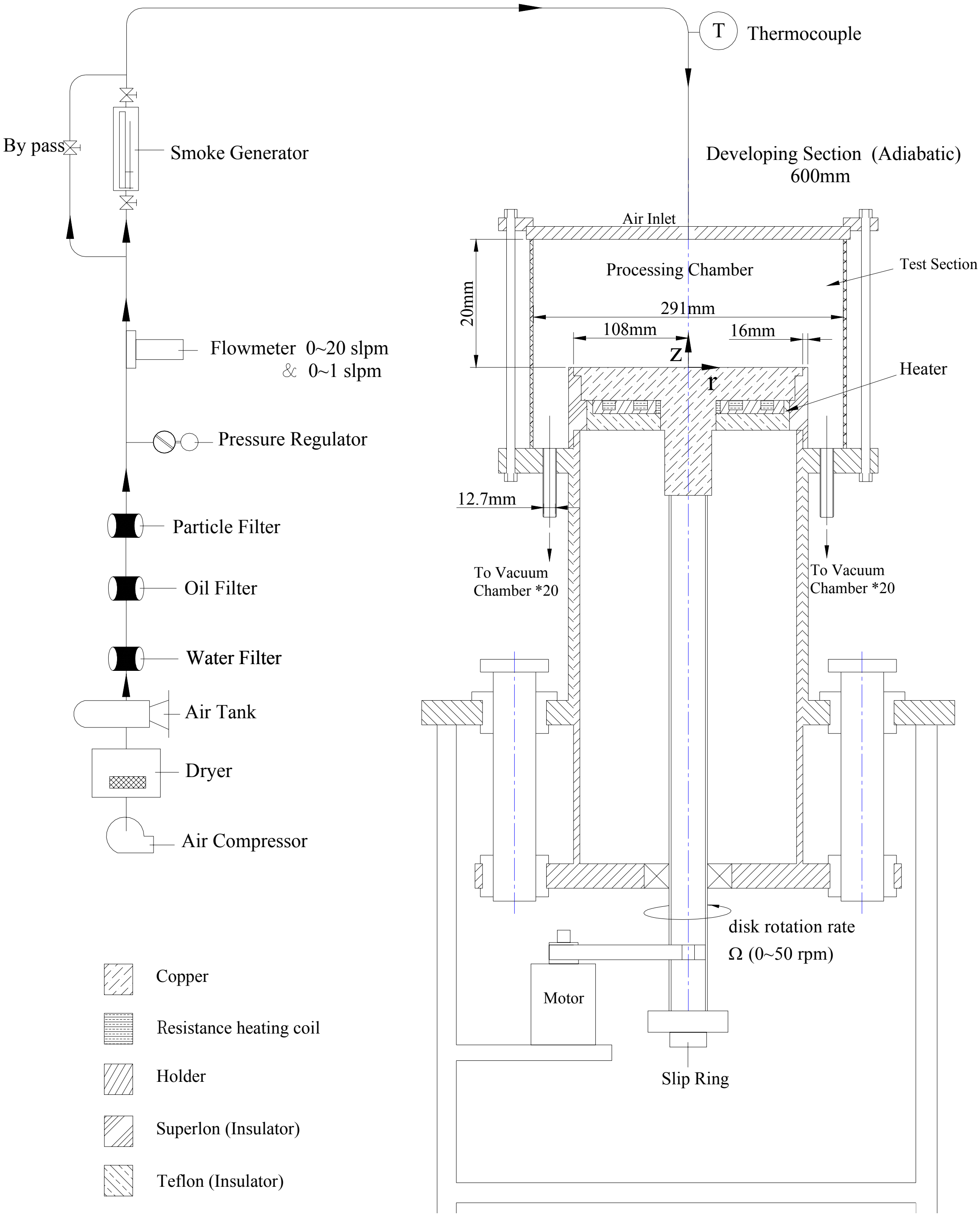
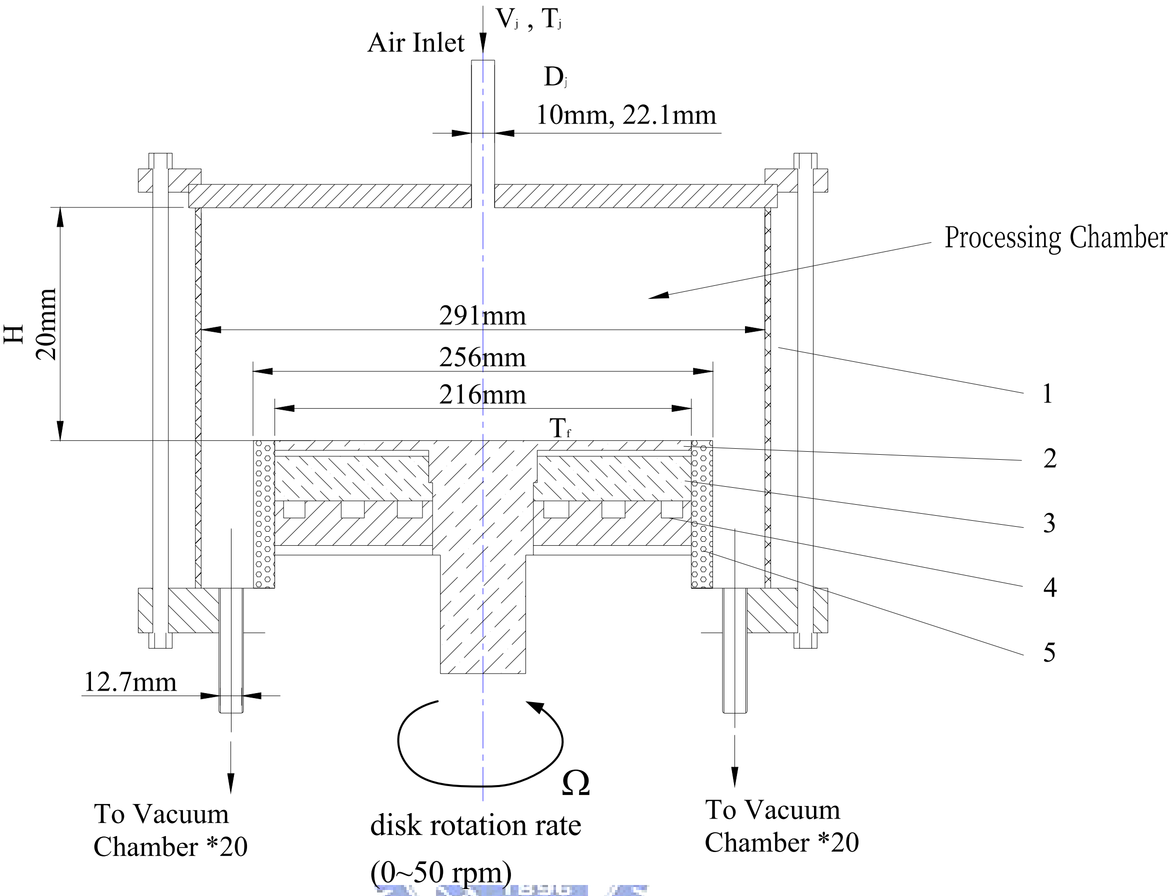


Fig. 2.1 Schematic diagram of the experimental apparatus.



1--Quartz Chamber
2--Upper Rotating Disk
3--Lower Stationary Disk
4--Heater
5--Insulator

Fig. 2.2 Schematic diagram of the test section.

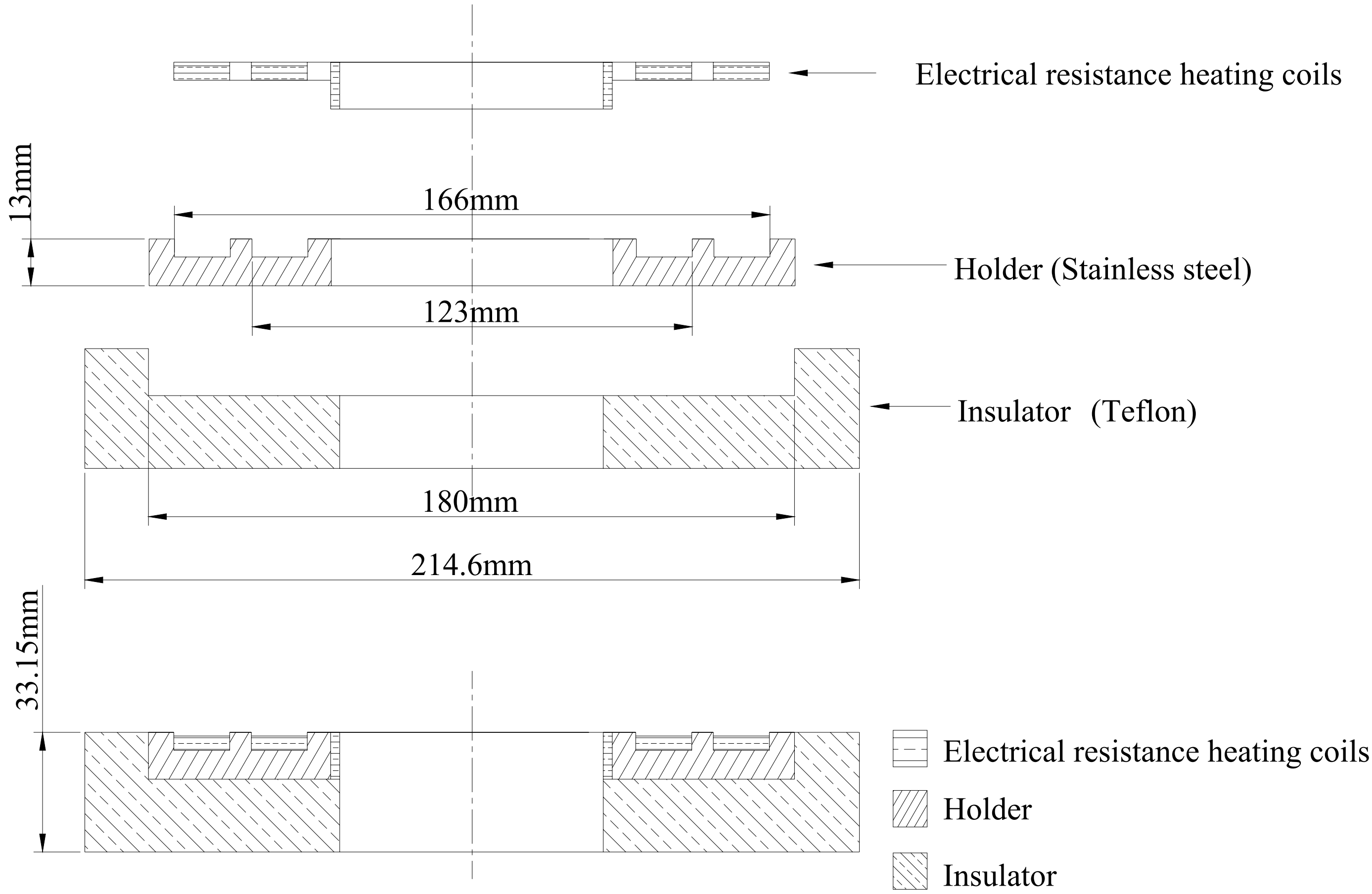


Fig. 2.3 The heater consists of three parts: resistance heating element, holder and insulator.

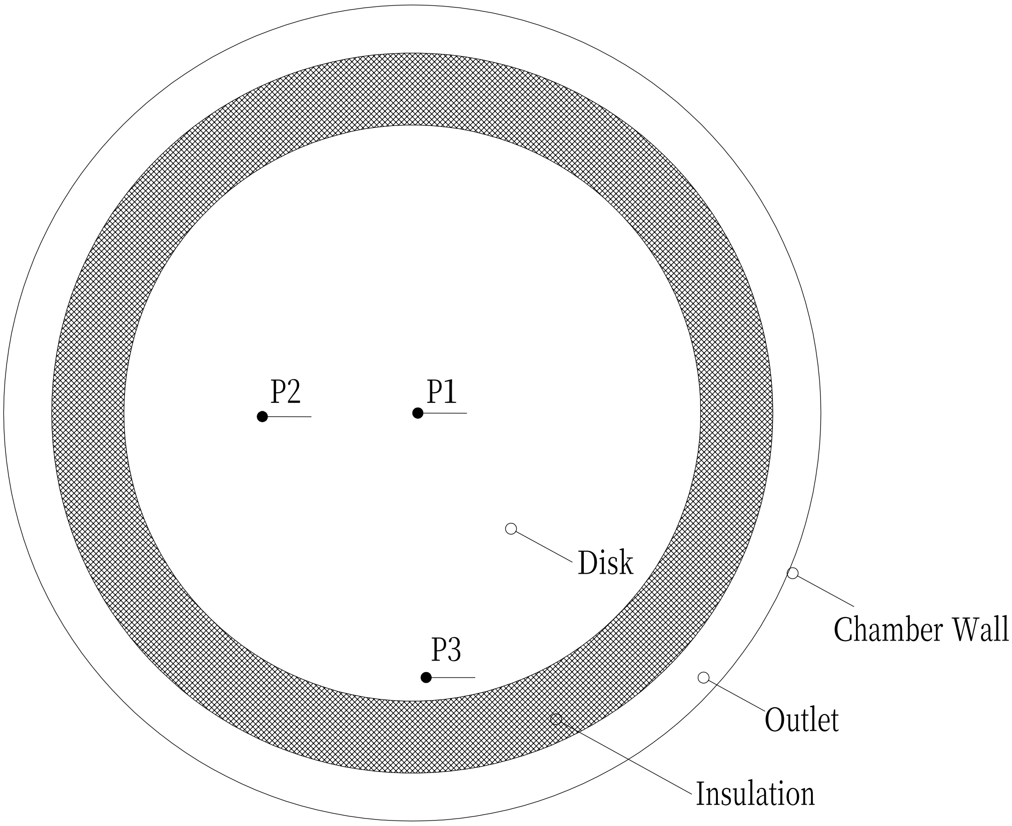


Fig. 2.4 The locations of the detection points on the upper copper plate.