Chapter III

Gas Measuring System

In this chapter, the design and construction of a gas measuring system will be discussed. The design system is a flow injection system. Gas measuring system is very important to determine the response characteristics of gas sensors. The details in each main components will be described.

3.1 Gas Measuring System

Fig. 3.1 shows a simplified schematic diagram of the gas measuring system. This system consists of five main parts as shown below.

- a gas flow control system
- an injector
- a test chamber
- measuring circuits
- data acquisition system

In this system, a mixed gas of oxygen and nitrogen was used as a carrier gas. Oxygen and nitrogen were industrial grade with 99.5 % purity which were purchased from Thai industrial gas Co. Ltd. The amount of oxygen or nitrogen in the carrier gas could be controlled through a set of valves in the gas flow control system. The ratio of oxygen to nitrogen was kept constantly at 20% of oxygen and 80 % of nitrogen through out the experiments[56]. A test sample could be introduced into the measuring system via the injection port equipped with a heater. After injection, the test sample was vaporized into the gas phase. The temperature of the heater is set at about 100 °C which is highly enough to vaporize the liquid sample in a few seconds. Then, the vaporized sample was passed to the test chamber at which gas sensors were installed. The temperature inside the chamber could be elevated from room temperature to 400 °C. The changes in resistance of gas sensors were detected by measuring circuit. The measuring circuit will be described in details later. The voltage signals were measured via a 12-bit A/D converter and monitored in a real-time using a personal computer. Computer programs for data acquisition and analysis data was developed using Pascal language. The software listings is given in appendix A. Fig. 3.2 shows the photograph of the whole system.

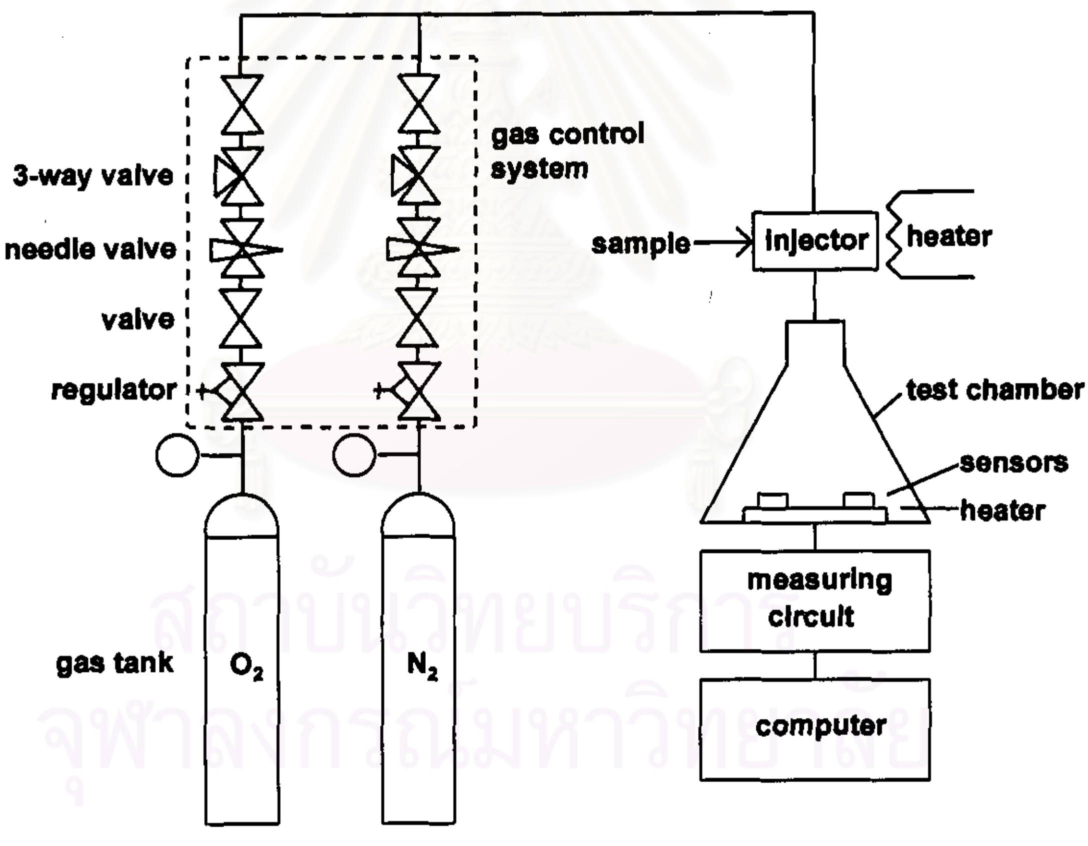


Fig. 3.1 Simplified schematic diagram of measuring system used in the experiments.

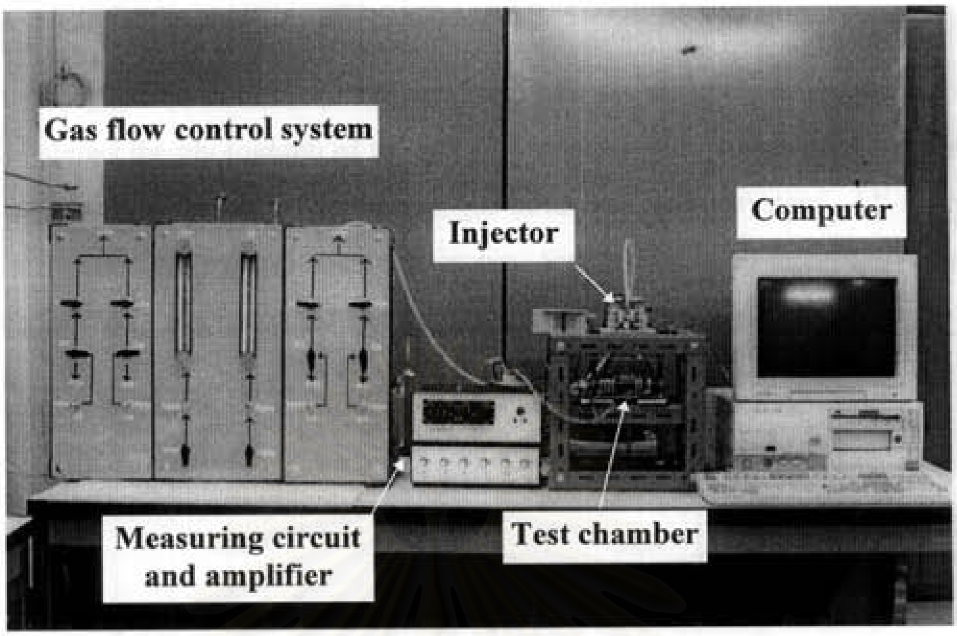


Fig. 3.2 Photograph of the constructed gas measuring system.

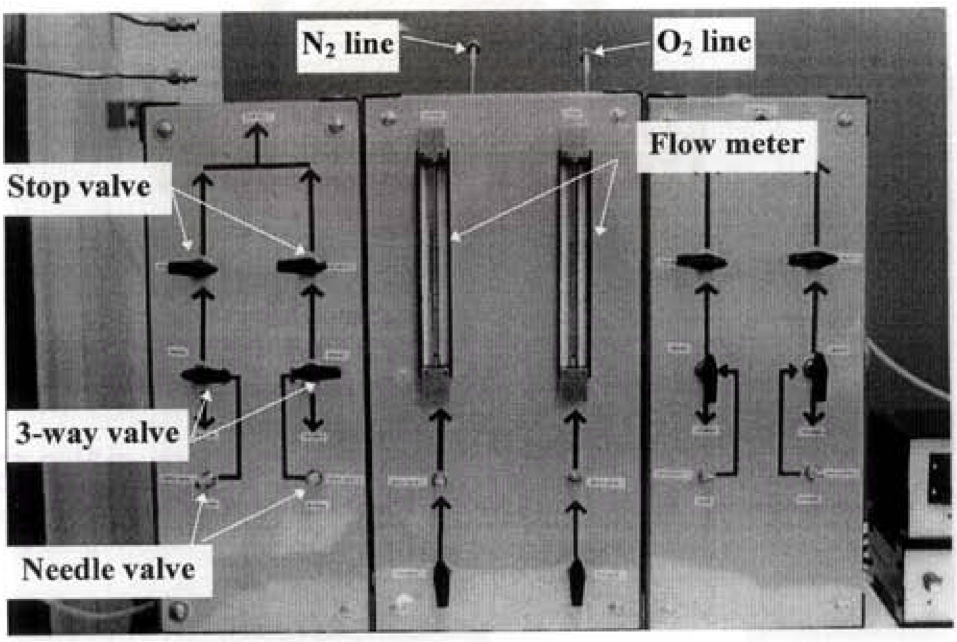


Fig. 3.3 Photograph of the gas flow control system.

3.2 Gas Flow Control System

The gas flow control system consisted of a set of valves as shown in Fig. 3.1. Fig. 3.3 shows the photograph of the gas flow control unit. It was used to control the paths and the flow rate of the individual gas in the measuring system. All fittings and pipes were stainless steel (standard ¼ inches, Swagelok). The three-way valves and needle valves in the gas control system were used to calibrate the gas flow rate.

3.3 Injector

The injector was used as an input port for the test samples. The structure of injector was shown in Fig. 3.4. The body of the injector was a three-way brass pipe. The test samples were injected through a silicon septum by a syringe. The temperature of the injector was controlled by two ceramic resistors (30 Ω 5 W) connecting in parallel. These resistors were supplied with 12 Vac.

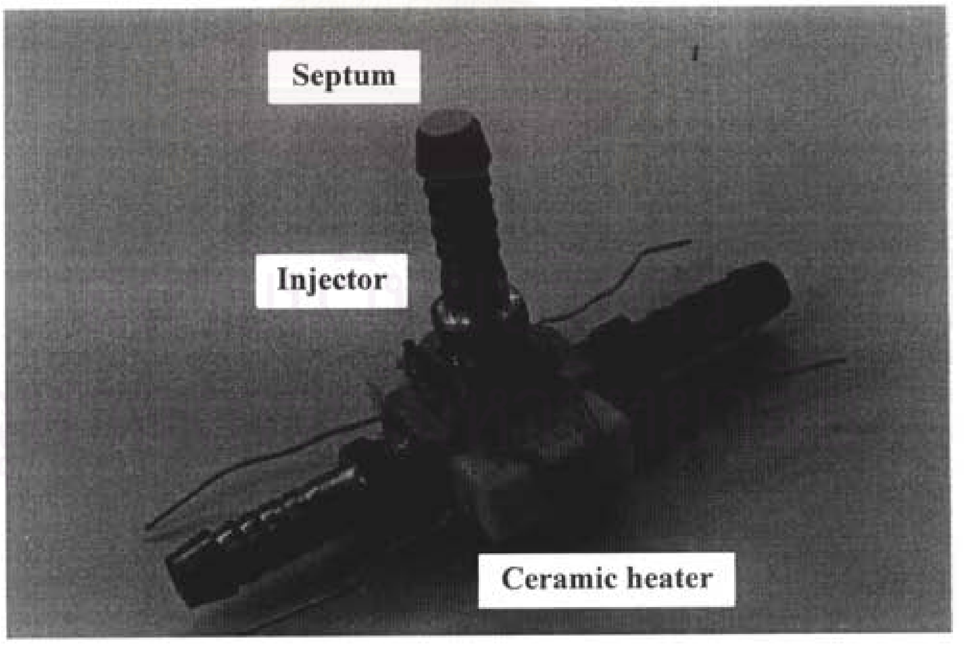


Fig. 3.4 Photograph of the injector.

3.4 Test Chamber

The schematic diagram inside the test chamber is shown in Fig. 3.5. The main body of the chamber was made of glass. An aluminium plate and a concrete block was used as a supporter for a heater and sensors. In this system, six sensors could be installed to characterize the gas response tests simultaneously. The arrangement of sensors was set in the circular manner to ensure that the concentration profile of a gas sample is uniform for all of gas sensors as shown in Fig 3.5(b). In general, gas sensors are operated at elevated temperature to avoid the changes associated with relative humidity[68]. Moreover, the temperature should be varied in a specific range. Thus, a heater was installed for controlling the operating temperature of gas sensors. A thermocouple type K was placed on the surface of the heater to monitor the temperature of gas sensors. It was designed that the heater could raise the temperature inside the chamber from room temperature up to 400 °C or more. Fig. 3.6 shows the photograph of the test chamber.

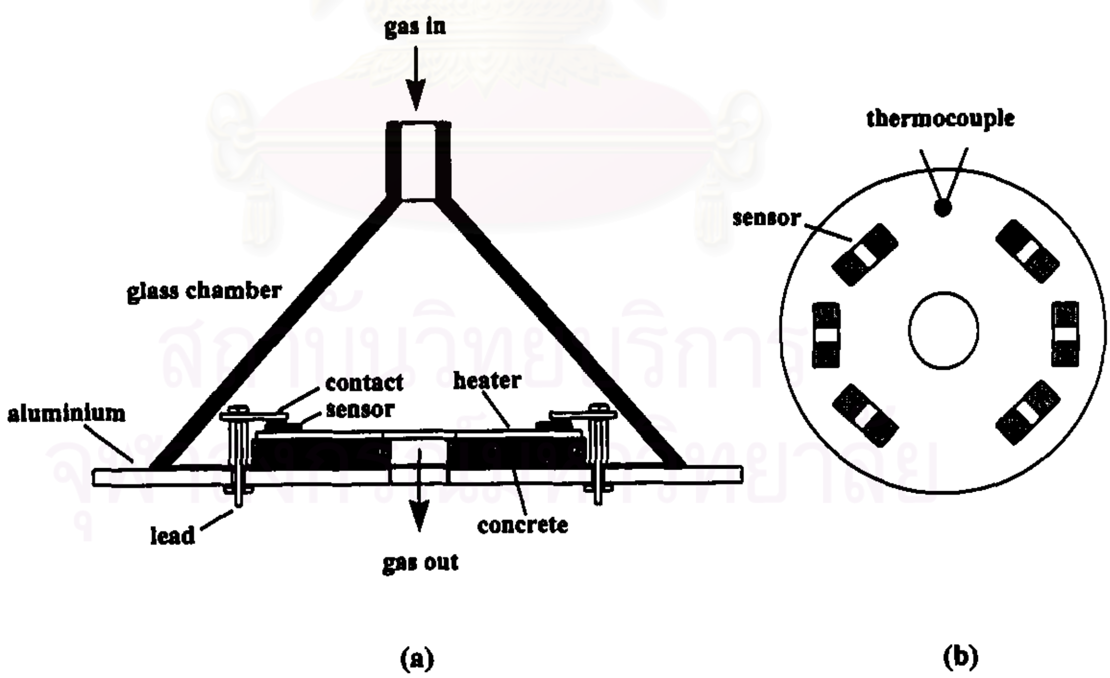
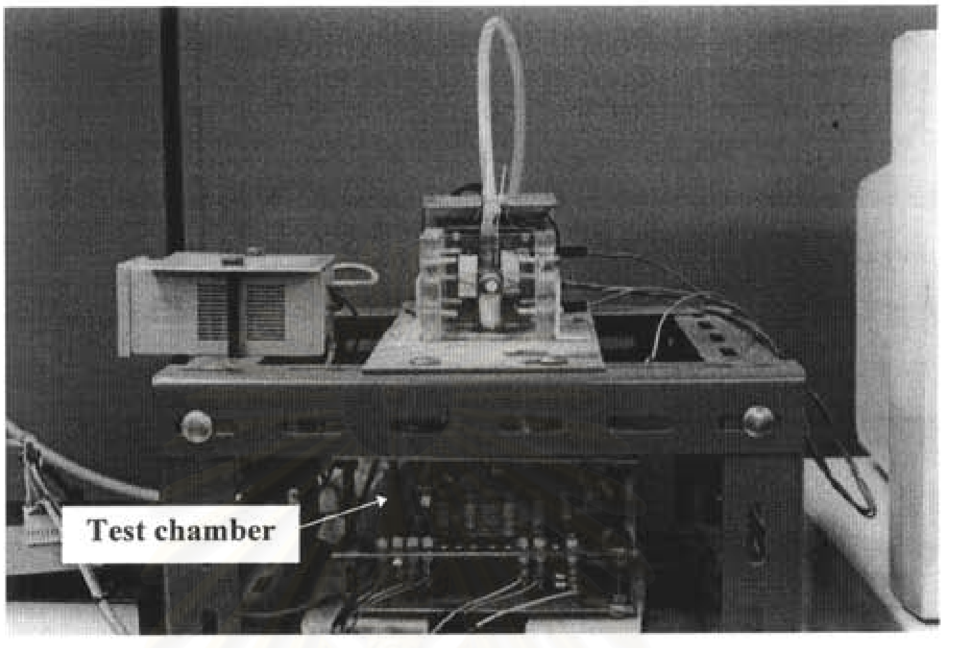
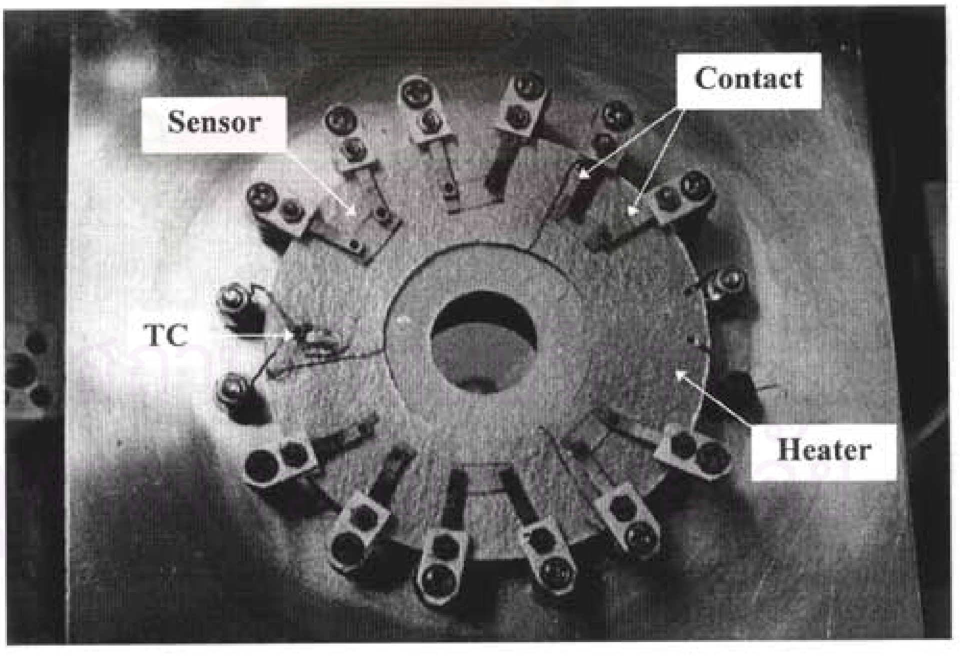


Fig. 3.5 (a) Schematic diagram of the test chamber; (b) top view shows the circular arrangement of gas sensors.



(a)



(b)

Fig. 3.6 Photograph of (a) the test chamber and (b) the heater inside the chamber.

3.4.1 Heater

The typical structure of heaters used in the experiments is shown in Fig. 3.7. The heater wire was an alloy of nickel/chromium (60/16) with a resistance of 14 Ω/m. Mica sheets were used as the insulator layers. Fig. 3.7 also shows the direction of the heater wire. It should be noted that this direction is important to the magnitude and profile of the temperature on the heater surface. Two features of the winding directions had been tried in our experiments. In type I, the heater wire was wound along the x-direction. In type II, the heater wire was wound in the radius direction.

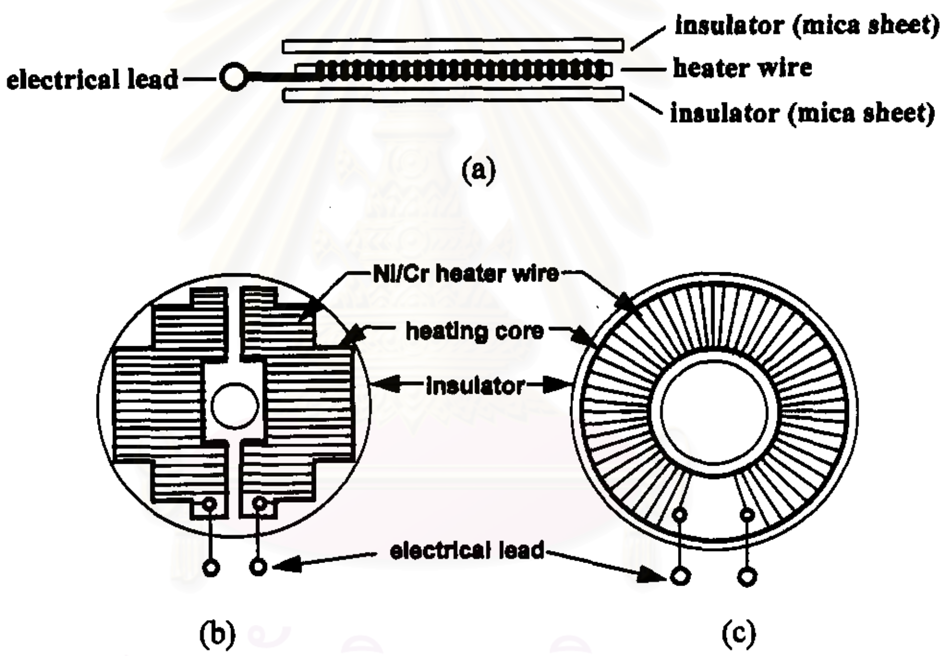


Fig. 3.7 (a) The cross sectional view of a heater; the arrangement of heating wire (b) the x direction (c) the radius direction.

The experimental results showed that in type I, there was too much temperature gradient and the temperature of gas sensors could not be raised to 400 °C. While, in type II, the desired temperature could be achieved. The relations between temperature and applied voltage of both heaters are given in Fig 3.8. The experimental

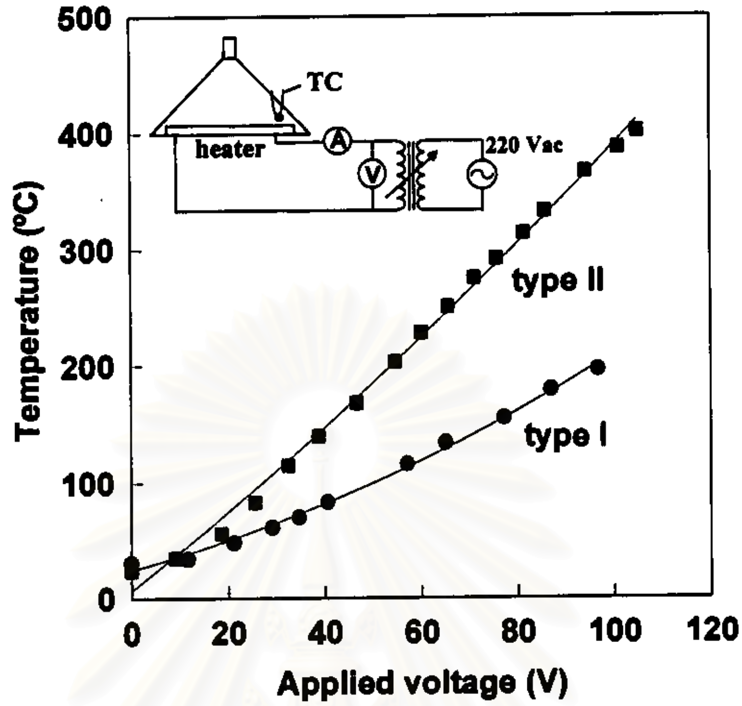


Fig 3.8 The temperature characteristics of the desired heater and the inset shows the experimental setups.

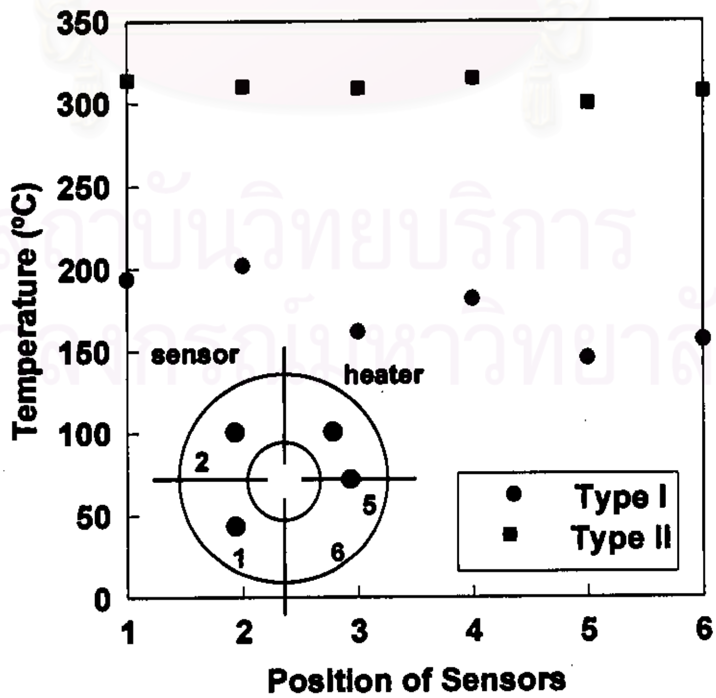


Fig. 3.9 Temperature profile of heater Type II

results showed that in type II, there were some temperature differences exist between sensors at different positions as shown in Fig. 3.9. However, these values were not so high, and should give no significant effect. The number shown on the x-axis in Fig. 3.9 corresponds to the position of sensor as can be seen from the inset picture.

3.5 Measuring Circuit and Amplifier

3.5.1 Measuring Circuit

Measuring circuits for calculating a sensor resistance are given in Fig. 3.10. There are two types of circuits used in the experiments. The first one is a conventional voltage divider which consists of a known resistance, R in series with a semiconductor gas sensor. The resistance of a gas sensor, R_s can be calculated form the voltage dropped across R, as given in eq. (3.1).

$$R_s = \left(\frac{V_{in}}{V_{out}} - 1\right)R \tag{3.1}$$

Where V_{in} is the applied voltage and V_{out} is the output voltage.

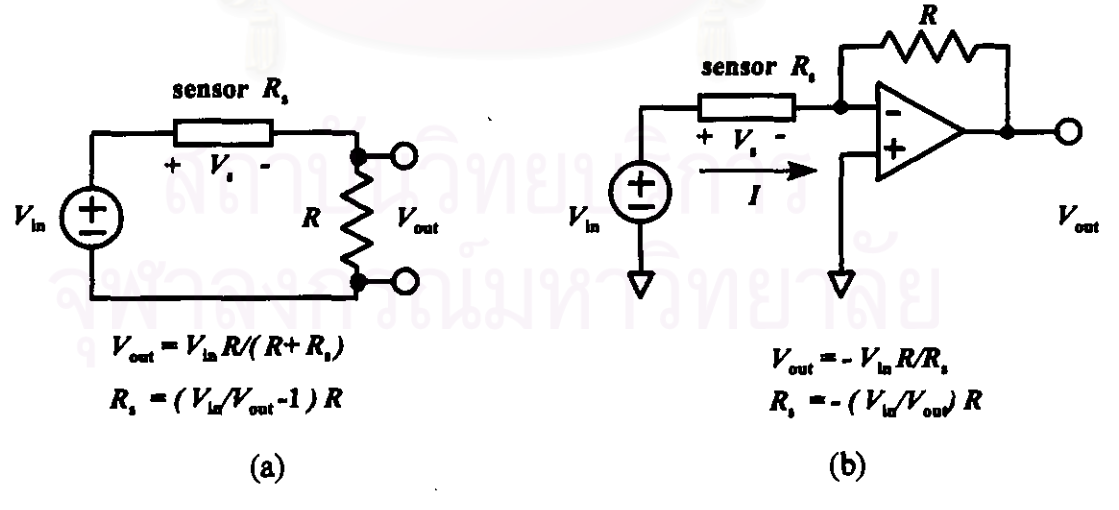


Fig. 3.10 Measuring circuit (a) the conventional measuring circuit; (b) our proposed circuit.

This circuit is very simple and suggested by gas sensor manufacturers. However, in this circuit, the gas sensor is assumed to have a linear current-voltage characteristic. Otherwise, the calculation of sensor resistance will depend on the value of R and V_{in}. The details of this dependency will be discussed in Chapter IV. Although, this circuit can be operated in a constant voltage mode, $R_s >> R$. In this range of operation, eq. (3.1) is reduced to eq. (3.2). However, this limitation rarely occurs in most practical applications.

$$R_s \approx \left(\frac{V_{in}}{V_{out}}\right)R \qquad (3.2)$$

This disadvantage can be compensated by our proposed circuit in Fig. 3.6(b). Indeed, this circuit is well known as the typical current to voltage converter. An electrode of a gas sensor is connected to V_{in} and the other is connected to the inverted input of an operational amplifier. Thus V_{in} appears constantly across the sensor electrodes under all circumstances, and R_s can be derived as follows.

$$R_s = -\left(\frac{V_{in}}{V_{out}}\right)R \qquad (3.3)$$

The results of eq. (3.3) is resemble to that of eq. (3.2). This means that the output voltage, V_{out} is directly proportional to the conductance of gas sensors at a fixed applied voltage, V_{in}. In general, V_{out} is a negative voltage. An additional inverting amplifier must be cascaded to the output stage of the circuit in Fig. 3.6b or a negative voltage source should be used instead.

Both of the measuring circuits described above had been tested and compared their performance, the results will be discussed in chapter IV.

3.5.2 Amplifier

Sometimes, the values of V_{out} obtained from the measuring circuit are too small to be measurable by an A/D converter. Thus, V_{out} must be amplified to the suitable region. To solve this problem, an amplifier was designed. The schematic diagram of the designed amplifier is shown in Fig. 3.11. The designed circuit has the specifications as shown in Table 3.1. Fig. 3.12 shows the photograph of the amplifier.

Table 3.1 Functions of the desired amplifier.

Function	
Filter	passive RC low pass filter with a cutoff frequency at 10 Hz
Gain	0.01,0.1,1,10 and100
Offset voltage	-10 to 10 V adjustable
Input impedance	> 10 MΩ
Input channel	6 channels with common ground input

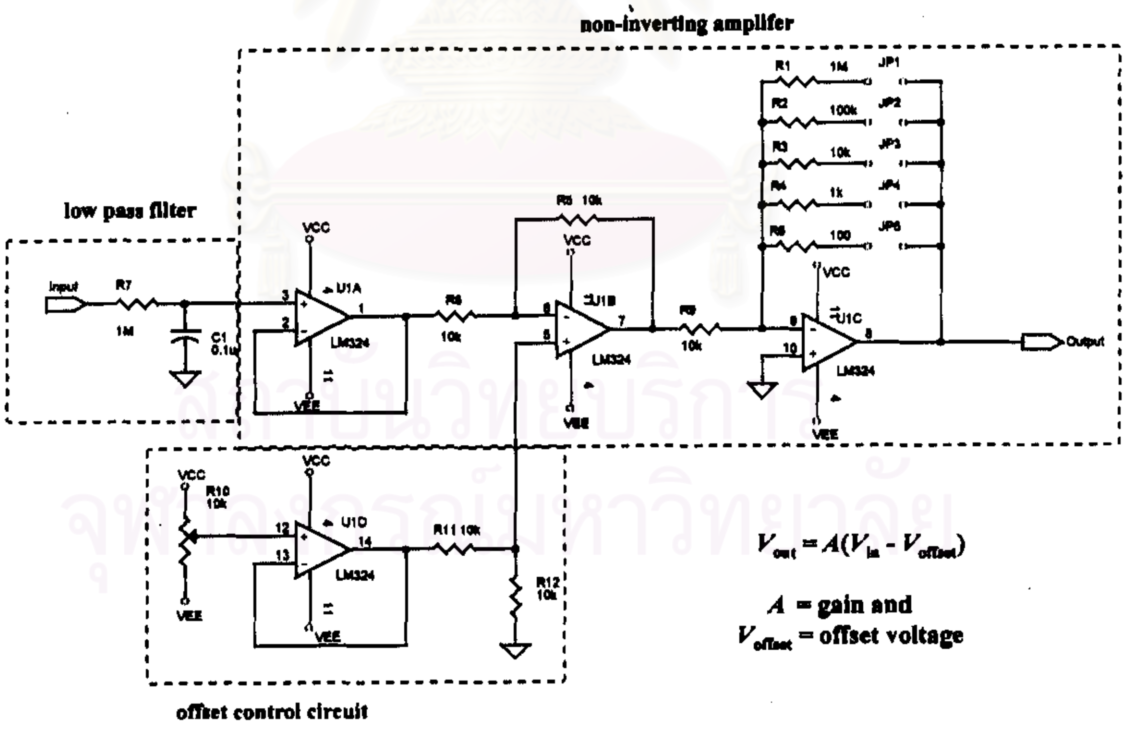


Fig. 3.11 Schematic diagram of the designed amplifier circuit.

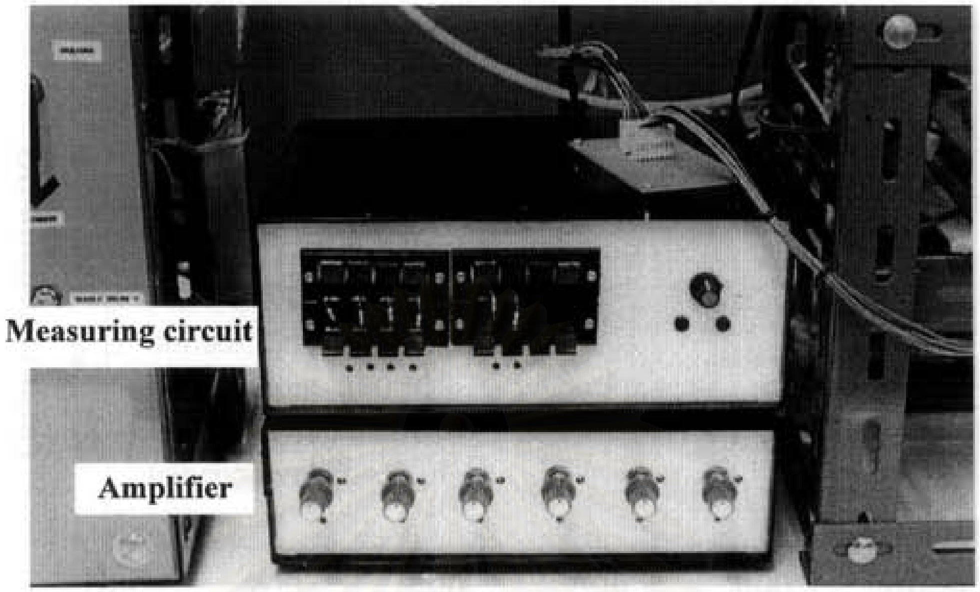
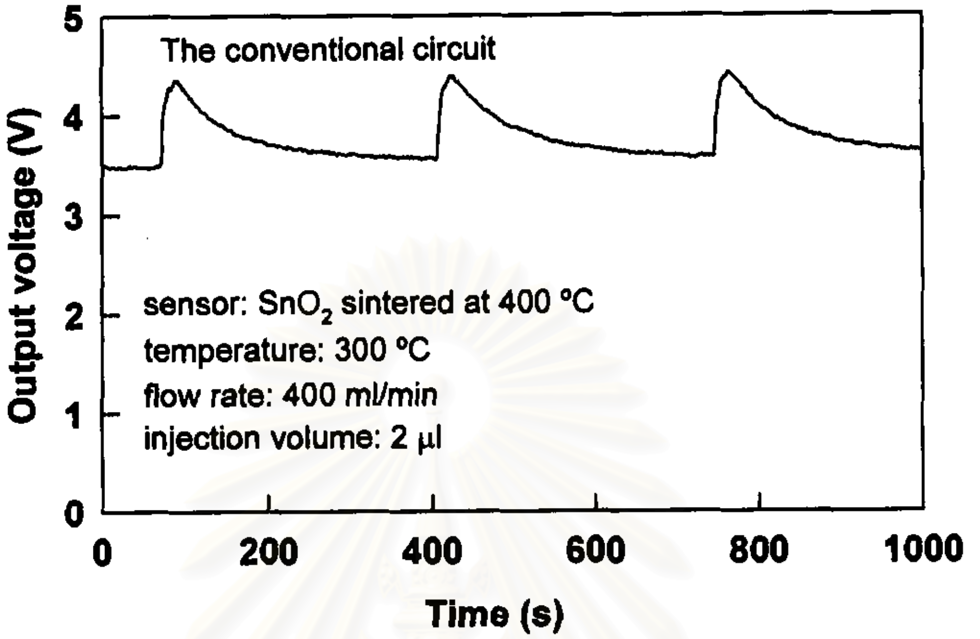


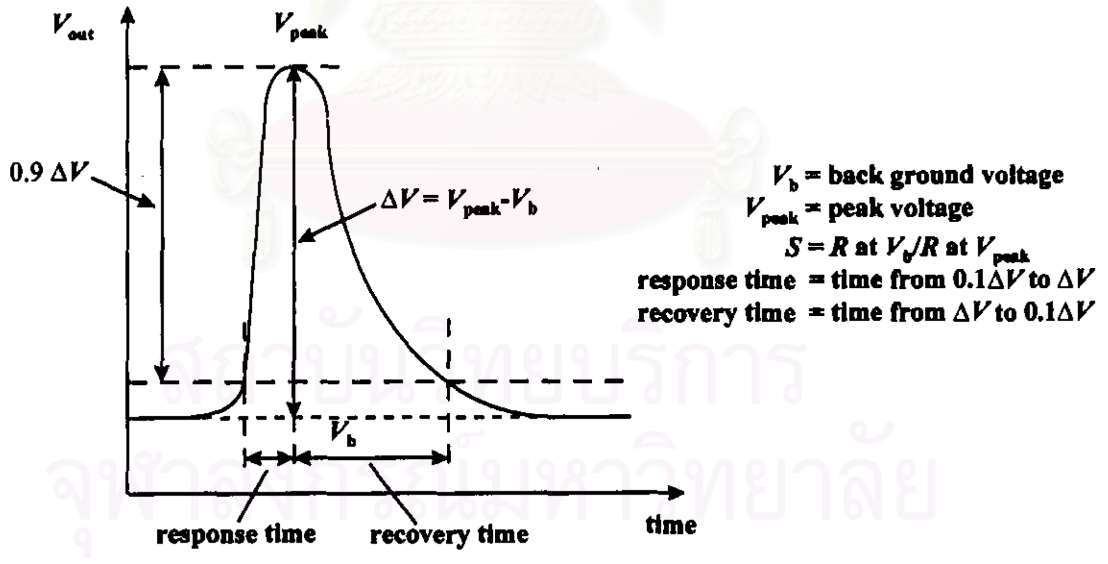
Fig. 3.12 Photograph of the amplifier and measuring circuit.

3.6 Test of Gas Measuring System

Fig. 3.13 illustrates typical response curves of a gas sensor obtained from the measuring system. The test sample was methanol 0.1 % by volume. The other testing conditions are shown in this inset in Fig.3.13(a). Sensitivity of a gas sensor is defined as the ratio between the sensor resistance in air to the resistance in the gas sample. The definitions of all important parameters involving in gas sensing are also included in Fig. 3.13(b). The system shows quite stable and reproducible response characteristics. The effect of injection volume and flow rate on gas sensitivity are shown in Fig. 3.14. The injection volume was varied from 2-10 μl, whereas the total flow rate was changed from 200 ml to 400 ml. From the results, it is clear that the sensitivity increases with the injection volume and the total flow rate of 300 ml/min gave the highest sensitivity. However, by considering the recovery time, gas sensors shows a substantial decrease in the recovery time at a flow rate 400 ml/m. Thus, the flow rate of 400 ml/min was chosen to use in all experiments. The injection volume was fixed at 6 μl.



(a)



(b)

Fig. 3.13 (a) Typical response curves obtained our measuring system; (b) definitions of important parameter in gas sensing.

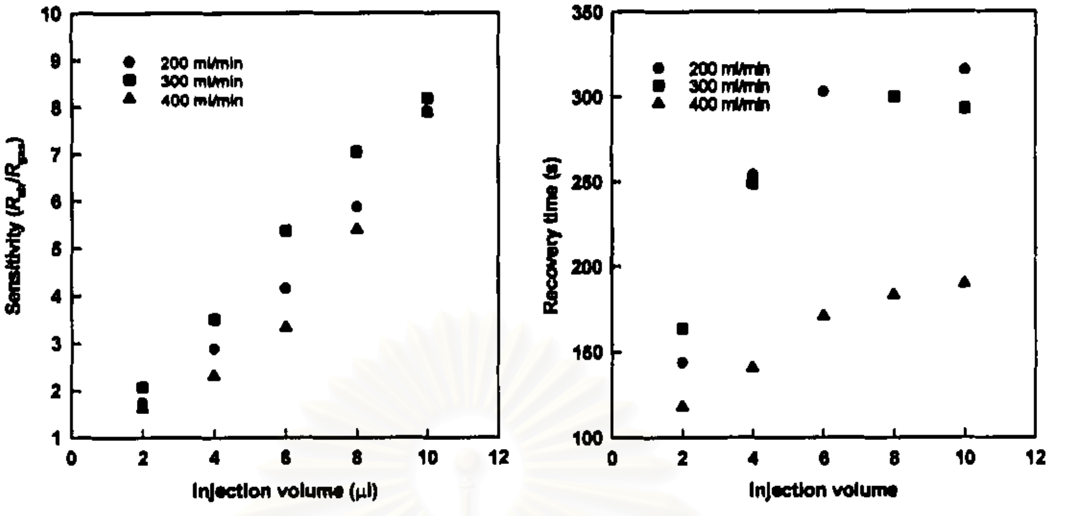


Fig. 3.14 The effect of the injection value on (a) gas sensitivity; (b) recovery time.

3.7 Summary

A flow injection system for testing gas response was designed and constructed. This system is able to control the important parameters in gas sensing characterization such as the total flow rate, the ratio of oxygen to nitrogen in a carrier gas and the operating temperature of gas sensors.