

An Instrument for Measuring the Gas Concentrations in Geothermal Wells

G. D. McDOWELL *

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ABSTRACT

An instrument and technique for rapid measurement and monitoring of gas concentrations in steam discharged from geothermal wells is described. The instrument directly measures the partial pressure of non-condensable gases present in a sample of the total discharge, at a given temperature and a given total pressure. This is achieved by deducting the vapour pressure of distilled water, at the same temperature, from the combined pressure of the water vapour and gases present. The volume of gas in the discharge can be obtained from the differential pressure by application of the ideal gas law with appropriate data from the steam tables. The percentage by weight of gas in the fluids can also be obtained if the chemical composition of the gases present is known. The results compare favourably with other methods.

Introduction

In many countries of the world natural reservoirs of hot water or steam are being tapped and utilized for electric power generation. The fluids in these systems contain non-condensable gases, the types and concentrations varying considerably between reservoirs. In the majority of areas, however, the predominant gas is carbon dioxide which frequently contributes over 90 per cent by weight of the total gas present. Other gases which are present in varying concentrations are, hydrogen sulphide, nitrogen, hydrogen, methane and other saturated hydrocarbons, inert gases and ammonia.

In the utilization of natural steam for the generation of electricity, it is economically desirable to utilize condensing turbines in the generating plant. As the majority of the gases present in the deep aquifer preferentially concentrate in the steam phase and are non-condensable, they must be extracted from the power station condensers by gas pumps, in order to sustain a vacuum. To design the requisite equipment and to maintain maximum power output from the unit requires a detailed knowledge of the gas concentrations in the steam.

During the course of exploitation, gas concentrations in a system may change and an accurate system for monitoring and recording gas concentrations in the discharges and steam reticulation lines is necessary. At Wairakei and Larderello — two major geothermal fields which have been extensively exploited — the gas con-

centration in producing wells decreases with time. At Larderello back pressure turbines exhausting to atmosphere are initially installed on wells but as gas concentrations decrease the wells are coupled to condensing units, thereby increasing power generation.

In New Zealand gas concentrations in geothermal wells have been measured and monitored by a chemical technique (MAHON 1961). A sample of steam, gas and water, taken from the total discharge of a well, is separated into its component phases by a small « Webre » cyclone separator. The steam phase is condensed and collected in an evacuated glass flask containing a solution of sodium hydroxide. Acid gases, such as carbon dioxide and hydrogen sulphide, are dissolved by the caustic solution leaving residual gases, such as nitrogen, hydrogen, methane etc., in the flask. The caustic solution is subsequently analysed to obtain carbon dioxide and hydrogen sulphide concentrations, whilst the residual gases are pumped off and determined by gas chromatography.

In the pressure range over which surface gas sampling is carried out, a high proportion of the gases (> 95%) is present in the vapour phase and the small amount occurring in the water phase can frequently be neglected, particularly in monitoring programmes. However, for really accurate gas determinations, water and steam samples are collected concurrently at the same pressure and separately analysed for their gas contents.

The major problem associated with chemical sampling of geothermal wells is that of obtaining representative samples of the discharge. MAHON (1961) outlined the standard techniques used in New Zealand for obtaining such samples and pointed out that the requisite conditions were sometimes difficult to meet in the exploratory stage, and in some cases, the production stage, of development. The time needed for collection of steam and gas chemical analysis can vary from 15 to 30 minutes, depending on the gas concentrations in the steam, and the analysed gas concentrations are an average for this period. Although relatively simple to apply, the chemical technique requires a skilled technician, reasonably sophisticated sampling equipment, cooling water and laboratory facilities.

* Chemistry Division, Department of Scientific & Industrial Research, Wairakei, New Zealand.

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To overcome some of the difficulties and disadvantages associated with the chemical method, and to obtain immediate gas concentrations, a physical technique was developed from an idea of Mr C. R. JAMES⁽¹⁾. In a steam-water-gas, or steam-gas, mixture flowing down a pipe, the pressure at any point is directly related to temperature and the partial pressure

methods of obtaining the partial pressure of the gases in the discharge were investigated.

The initial method investigated was by temperature measurement. Accurate temperatures within a discharging borehole, at different total pressures, were taken with a « Casella » master thermometer. The water vapour pressures were obtained at the measured

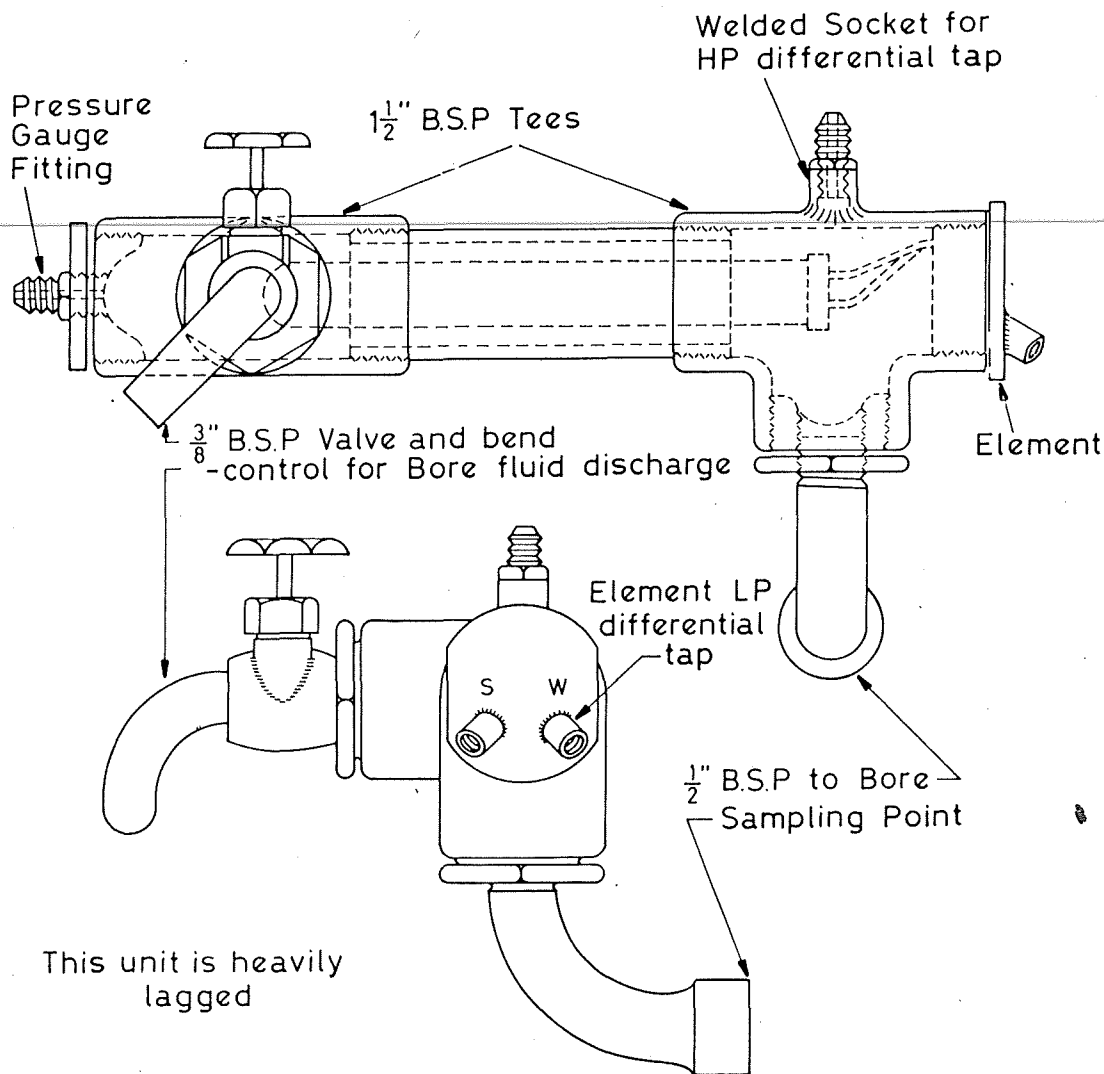


FIG. 1. — Element casing.

of the gases present. It is assumed that thermal equilibrium is maintained in the mixture at all times. Total pressure P_t can be expressed as $P_t = P_v + P_g$ where P_v is the vapour pressure of water at temperature t and P_g is the sum of the partial pressures of the gases. If the partial pressure of the gases in the mixture can be measured, application of the ideal gas law, using the properties of saturated steam for obtaining the volume, allows the volume percentage of gas in steam at a particular total pressure to be obtained. Two direct

temperatures from steam tables and were subtracted from the total pressures, which were recorded on an accurate gauge attached to the pipe at the points of temperature measurement. These differences in pressures correspond to the sums of the partial pressures of the gases. This method was satisfactory only in cases where the gas content of the discharge was high and the pipe line pressure completely stable. Another associated problem was the tendency of thermometer pockets to shear and break, after short periods of exposure, due to the continual impact of the two-phase mixture.

⁽¹⁾ Chemical engineer, Chem. Div., D.S.I.R., Wairakei, New Zealand.

The second method investigated involved a direct measurement of partial gas pressure by a differential pressure technique. Consider a sealed steel vessel, partially filled with degassed distilled water, immersed in the well-head piping of a discharging geothermal well and in thermal equilibrium with the flowing fluid. The pressure within the vessel is slightly less than that of the steam-water mixture in the discharge pipe

Description of apparatus

The introduction of a vessel into the main discharge pipe of a well presents several problems. These were overcome by constructing an apparatus into which a portion of the discharge from the main horizontal bypass pipe was diverted. Figure 1 shows the apparatus designed for the experiments. Well fluid is sampled from the main pipe through a standard sampling point

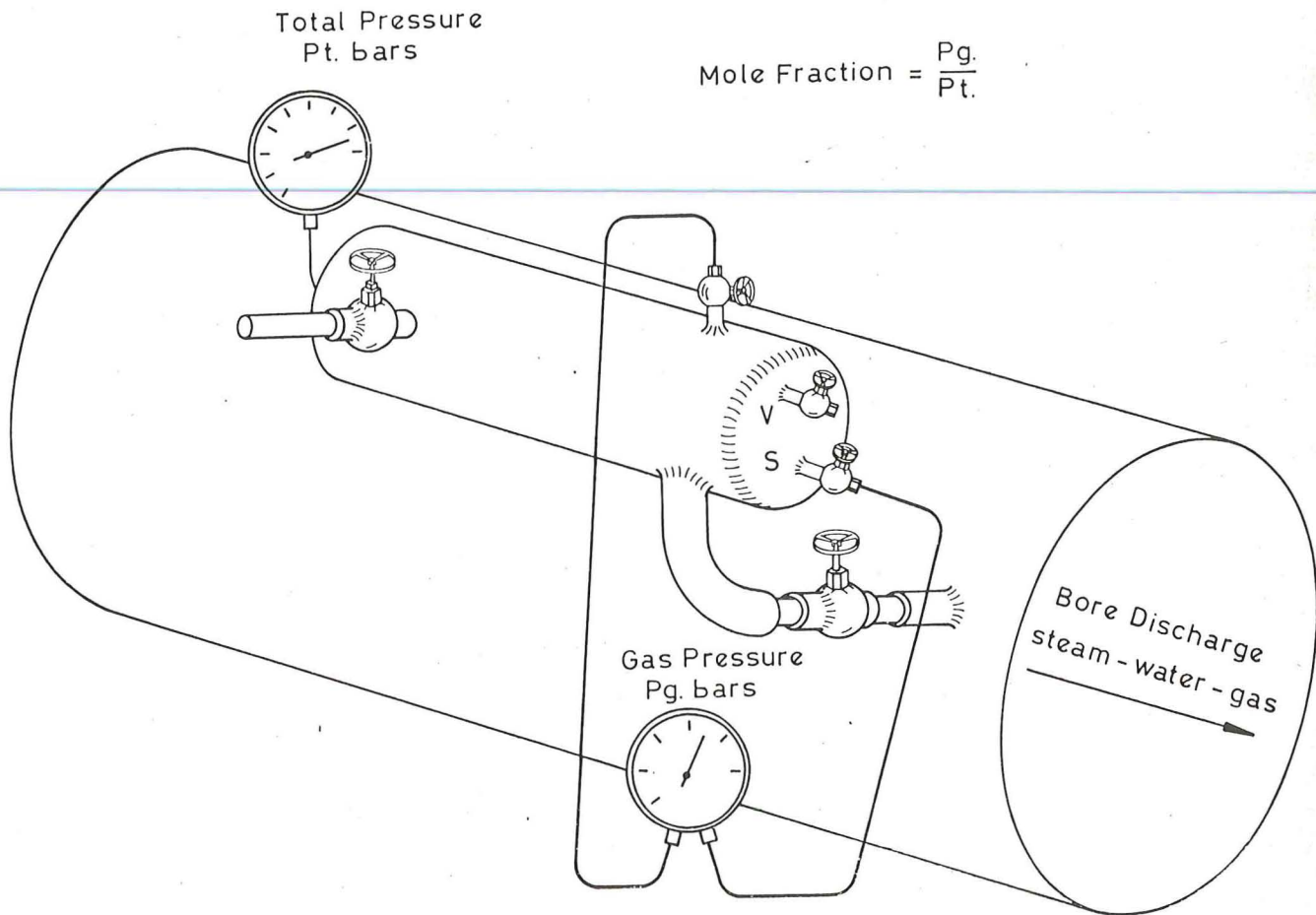


FIG. 1a. — Schematic arrangement of gas probe in use.

due to the non-condensable gases present in the latter. On connecting the vessel to one arm of a differential gauge and the well pipeline to the other arm, the partial gas pressure is obtained. As this value is read directly, errors are greatly reduced compared with the temperature-pressure method where any error in gauge reading is transmitted directly to the partial pressure. This error can be considerable, in particular where gas content is small, and hence the partial pressure reading low.

This second method appeared promising and an apparatus for making the measurements was designed. It was essential that equipment designed for this work should be readily portable, robust and self-contained, the latter requirement being necessary in view of the inaccessibility of a great number of the geothermal fields at present under investigation.

(MAHON 1961) and passed through a heavily lagged cylindrical casing containing the distilled water element. The casing inlet is much larger than the outlet ensuring that a negligible pressure-drop occurs within the unit yet at the same time maintaining a large enough flow to ensure that conductive heat losses are minimal. Figure 1a shows a schematic arrangement of the sampling probe in operation.

The element (Figure 2) is positioned in the fluid flow by means of its differential and venting tubes which enter a screwed plug which forms one end of the casing. The plug has incorporated heat traps, for each of the two element tappings, together with a small flow needle valve fitting for each. The important design feature within the unit is the heat trap plug. Earlier experimental units having direct tappings to the ele-

ment were found to have a differential oscillation due to the « bumping » of condensing steam in the vent tube. With the present design, stabilization occurs after a short period of several minutes. The steam-water interface is relatively stable since it is located in the near vertical drillhole of the plug which retards thermal convection.

To overcome the necessity of continually installing thermometer pockets in the main discharge pipeline, a condensation chamber was modified, Figure 3. A thermometer pocket was installed in the top vent of the chamber, the feed was extended to match a standard sampling point and the meter leg diameter was increased to the same dimensions as the differential

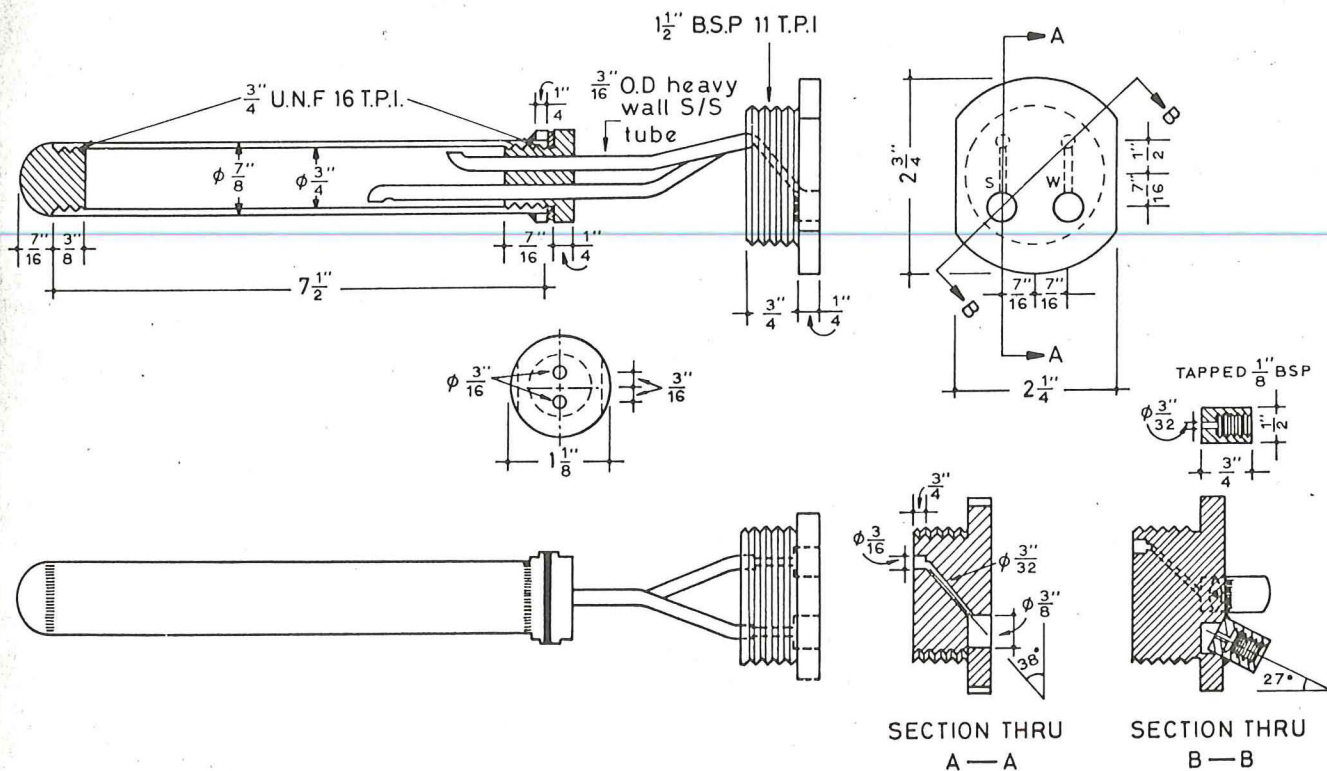


FIG. 2. — Gas measuring element. 18/8 Stainless steel.

Differential pressures are measured by inverted water manometers, for very low gas contents, and mercury under water manometers or pressure differential gauges for higher gas contents. The pressure gauges used at Wairakei are Budenberg « Microvar » diaphragm differential gauges which are very accurate and robust.

The apparatus was tested under field conditions on wells at Wairakei and Broadlands. During tests on several high-gas content wells at Broadlands, when both physical and chemical methods were employed, it was found that up to a 20% difference between the two methods occurred. It must be appreciated that in the chemical method selective sampling of the water phase can take place by the Webre separator at low enthalpies, particularly where pipe geometry is such that this phase is concentrated at the sampling point. Should the water fraction be high, dilution of the steam may occur through water flashing during passage through the separator, a difficulty the direct partial pressure reading method overcomes. To check the results by an independent method, temperature readings were compared against the measured pressures.

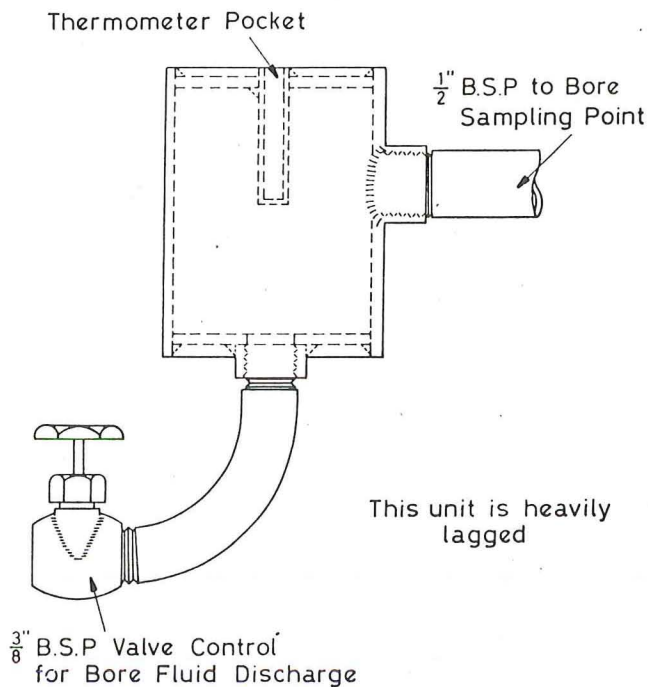


FIG. 3. — Modified condensation chamber.

device casing discharge. Pressures were read from a Budenberg stainless steel tube gauge, calibrated before and after each series of runs, and temperatures were recorded on a Casella master thermometer, reading to 0.1°C.

Excellent agreement of partial pressures was obtained between the direct reading partial pressure device and the temperature-pressure device. It was apparent that there was no significant error due to instrumental construction or operation.

Calculations

The combination of Boyle's and Charles' laws give the general equation $PV = nRT$ known as the ideal gas law. At the pressures and temperatures at which the partial pressures of gas are measured in the described method the deviation from perfect gas conditions is small and can be neglected (COOPER, MAASS 1931).

If n is in mole of total gas per mole of steam, then

$$n = \frac{144 P_g V_s 18}{1445 T} \quad (\text{British Units}) \text{ or}$$

$$n = \frac{P_g V_s 18}{83.13 T} \quad (\text{S.I. units})$$

	Brit. Units	S. I.
Where P_g is partial gas pressure	p.s.i.	bars
T is absolute temperature	°R	°K
V_s is specific volume of steam	ft ³ /lb	m ³ /kg

When the composition of the gas phase is known, an average molecular weight M_a can be calculated and the equation can be used to calculate the weight of gas per pound of steam.

$$W (\text{lb}) = \frac{M_a 144 P_g V_s}{1545 T} \quad W (\text{kg}) = \frac{M_a P_g V_s}{83.13 T}$$

Good agreement has been reached with the chemical method in wells with high discharge enthalpies, where the chemical sampling Webre separator draws a more representative sample and minimal dilution of the steam occurs during the separation pressure drop.

It must be emphasized that complete agreement between the two methods can only occur when a full analysis of the gases in the steam is available as the partial pressure method gives a mole value for all gases present

METHOD

Sample calculation

Broadlands Bore 21

Sampling pressure	P_g 11.2 bar
Partial pressure reading gas	P_g 349 mm/H ₂ O = 0.43 bar
Partial pressure of steam	P_s = 10.8 bar
Temperature of steam	T = 456° K
Specific vol. of steam	V = 181 m ³ /kg
Universal gas constant	R = 83.13

$$n = \frac{P_g V_s 18}{RT} = \frac{0.43 \times 181 \times 18}{83.13 \times 456} = 0.037$$

Chemical determination of CO₂ + H₂S gave a value of 0.0357. From a gas analysis (MAHON, FINLAYSON 1972) of the well fluid an averaged molecular weight for the gases was obtained of 42.74. Inserting this value in the weight formula gave the following result:

$$W = \frac{M_a P_g V_s}{83.13 T} = \frac{42.74 \times 0.43 \times 181}{83.13 \times 456} = 0.088 \text{ kg gas/kg steam}$$

Chemical determination of CO + H₂S gave 0.0868 kg gas/kg steam. The following list, Table 1, shows a comparison between the chemical results and the direct reading physical results on a selection of wells. It is to be noted that in the chemical results only CO₂ and H₂S are listed. The molecular weights are an average of published results (MAHON, FINLAYSON 1972).

TABLE 1. — Comparison between chemical results and direct reading physical results on a selection of wells.

Well	Sampling pressure bars	Enthalpy J/g	Physical method		Chemical method		
			Gas total m/m	% gas/steam	Gas total CO ₂	Total m/m H ₂ S	% gas/steam
21	10.8	1914	.03714	8.8	.03525	.00046	8.6
19	9.1	2559	.04800	11.4	.04226	.00049	10.3
8	7.8	942	.05580	13.5	.04947	.00045	12.13
7	9.8	2063	.02820	6.8	.02512	.00022	6.17

Conclusion

Determination of the gas content of the discharge from a geothermal well by direct measurement of the partial pressure of the gases present is a feasible proposition. The method has advantages over the standard chemical analysis method and enables direct, rapid and continuous results to be obtained. A combination of both physical and chemical procedures allows a versatile system of gas monitoring to be carried out.

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REFERENCES

- COOPER D. L. B., MAASS O. 1931 — Density of carbon dioxide. *Canad. J. Sci.*, v. 2, 283.
- MAHON W. A. J. 1961 — Sampling of geothermal drillhole discharges. *Proc. U. N. Conf. New Sources Energy, Rome*, v. 2, 269.
- MAHON W. A. J., FINLAYSON J. B. 1972 — Chemistry of Broadlands geothermal area, New Zealand. *Amer. J. Sci.*, v. 272, 48.