Some Technical Aspects of CO_2 Enrichment

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INTRODUCTION

The subject to be dealt with is divided into three parts. In the first chapter several aspects of CO_2 apparatus will be discussed. In the second chapter we will look at the distribution of CO_2. In the third part attention will be paid to the CO_2 concentration, which is a function of distribution.

APPARATUS

Demands upon the apparatus. In view of human health, in many countries demands are made upon the concentration of gases in the working environment. Some of these gases occur in the combustion from burners, which are used for CO_2 enrichment. This implies that burners should not produce too much of harmful components. The demands are expressed in the so-called MAC values (maximum allowable concentration), at which labourers can work without harm during 8 hours every day.

Plants are also sensitive to some components of flue gases, where certain concentrations are exceeded. But the harmful concentrations for man and plant are different. This is shown in the following example. The MAC value for CO is 100 ppm (see Table 1). This means that a burner with the combustion gases not piped to the open, should give no rise of the CO-content beyond 100 ppm. With regard to CO, plants are less sensitive than men. Beyond values of 500 ppm we may expect phytotoxical effects. In many cases plants are far more sensitive than human beings. For example MAC-values for SO_2, NO_2, NH_3, O_3 and formaldehyd are 5, 5, 50, 0.1 and 5 ppm, respectively. But for plants the maximum tolerable concentrations for the same substances are 0.2, 20, 10, 0.2 and 0.7 (see Table 1). Plants are said to be very sensitive to ethylene (Crocker et al. 1932). At concentrations of about 0.05-0.10 ppm, injury on tomato plants should occur. However, recent fumigation experiments showed that tomato plants are less sensitive.

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Table 1. Some MAC values and some critical values for plants (ppm)

	SO_2	NO_2	NH_3	O_3	CH_2O	CO	C_2H_4	C_3H_6
MAC values (ppm)*	5	5	50	0.1	5	100	—	—
Critical values for plants (ppm)**	0.2	20	10	0.2	0.7	500	0.05	50

*Taken from Archives of environmental health, 1964.
**Taken from Thomas, 1961, but for CO and C_3H_6 from Crocker et al., 1932.

But not only for human health, also for possible danger from explosion certain demands are made. Distinct rules are given especially on the equipment for gases, such as propane.

Incomplete combustion. Incomplete combustion can be brought about in two different ways: (a) The burners do not work well, because of bad construction, pollution or wrong relation between air and gas supply. (b) Gas from leakages streams along the outside of the flames of the burners. Some aspects of incomplete combustion are:

1. Products of incomplete combustion. The main products of combustion are carbon dioxide and water. But combustion gases always contain minor quantities of other products such as carbon monoxide, aldehydes, ethylene, nitrogen oxides and propane or methane. The better the combustion, the lower the contents of these minor components.

2. Injury to plants. Several cases of plant injury are known. They were always caused by burners which did not work properly, or were caused by leakages in pipes or pipe-connections. The most striking case was with tomatoes. One set of burners out of a range of 22, all supplied with natural gas, stopped working in the night, while the others kept working normally. The following morning all plants were badly injured. The oldest leaves had been burnt, younger leaves were partially damaged. Damage might be aggravated by the presence of temperature radiators above the plants.

All other known cases of damage were less severe and arose more gradually. On cucumbers we saw leaves gradually yellowing—at first the oldest, later on the younger leaves. The same was observed on tomato plants, where abortion of trusses also occurred. In both cases damage was done by leaking of the gas. Yellowing of leaves and abortion of trusses were also observed when burners worked badly. After incomplete combustion of natural gas, ethylene appeared to be present in relatively higher concentrations than other harmful components.

3. How to prevent injury. (a) The total equipment should be installed by reliable firms. The best burners should be mounted and

the best materials employed. (b) Good service must be given. At least once a year the total installation should be tested to be sure everything is in a good working condition. (c) Stop CO_2 enrichment when an acid smell is perceived, which indicates that something must be wrong. Call the installer to repair the burner or the installation. Even with very little incomplete combustion, one can detect the characteristic smell. (d) Buy only burners which are certified as reliable. This certificate must be issued preferably by an official bureau. In the Netherlands proposals have been made for the foundation of a bureau, where all burners for CO_2 enrichment will be tested on the presence and quantity of harmful components in the combustion gases. Only certified burners should be used in horticulture.

Appliances for paraffin. There are two different burning principles. The first is known as burning by evaporating. A well-known representative is the "hylo" (see Fig. 1). In the beginning of the CO_2-boom in 1961 this was the only paraffin burner. It was not suitable for automatic control and the maintenance costs were high. Besides it did not work very reliably. This type is gradually pushed aside by a type of burner based on another principle: burning by automizing the paraffin, with a fan to provide a desired air stream. It is automatically controlled and works very well (see Fig. 2).

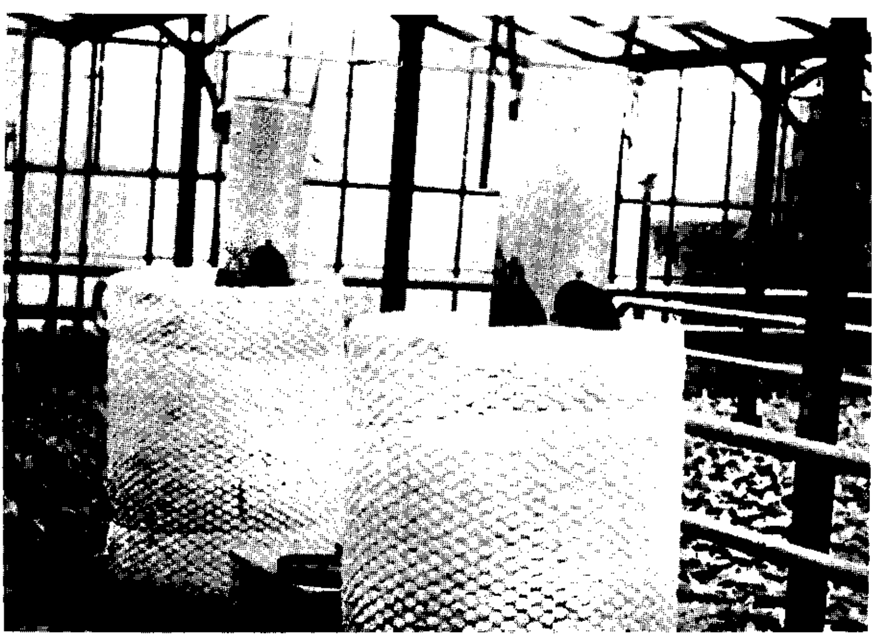

Fig. 1. Paraffin evaporating burner.

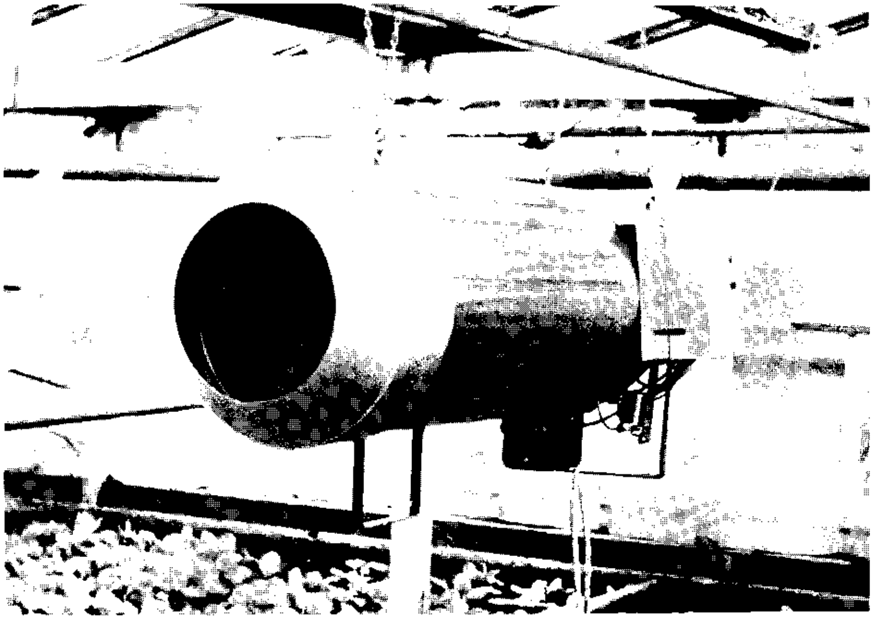

Fig. 2. Paraffin atomizing burner.

Appliances for propane. Many propane appliances are available. Mentioning all of these is not necessary. The combustion of the different propane burners can vary greatly however. On this field we feel a strong need for a bureau which will test all burners. The construction is based on two principles. On one hand there are high pressure burners with pressures for propane of 1 or 2 kgf/sq cm. There is a single gas outlet, and there is but little chance for pollution. Safeguarding is easy and reliable. When it is in use, it makes an annoying noise; this appeared to be an objection to this type of burner.

On the other hand there are low pressure burners. The gas pressure is lower than 30 gf/sq cm. Always a number of gas outlets have been joined to one unit. The construction may easily lead to plugging, but there is no annoying noise. Many types are known.

Appliances for pure CO_2. In most cases pure CO_2 is supplied from a battery of steel bottles or some other container. The CO_2 is led to the cultural space, where it flows from very small orifices (interspaced at 30-60 cm) in plastic pipes.

DISTRIBUTION OF CO_2

The CO_2 which is brought into glasshouses must be distributed as uniformly as possible. To achieve this one can: (1) Use a fan; (2) leave the distribution to convection, which will arise by temperature differences between combustion gases and glasshouse air; or (3) leave the distribution to diffusion and accidental air movement caused by insolation, heating pipes and wind speed.

With paraffin as a CO_2 source, a fan is always used because only a large apparatus is employed. With propane, small units are common and convection is the only way of distribution.

From CO_2-readings it appeared that one fan of a good capacity can give a good distribution when the glasshouse area does not exceed about 3000 sq m. On larger areas more fans are necessary. When making use of convection a uniform distribution of CO_2 will be obtained, when an apparatus is installed at about every 500 sq m. The distribution from diffusion only is very poor. Only in a restricted area near the CO_2-outlet a clear increase in CO_2 concentration will occur. For this reason a large number of CO_2-outlets is necessary in a glasshouse. This is illustrated with Fig. 3.

In a Dutch vinery house (8 x 70 sq m) two propane burners without fans were installed at about 18 and 54 meters from the front wall along the length of the house. In an identical house pure CO_2 streamed out of two openings at corresponding places.

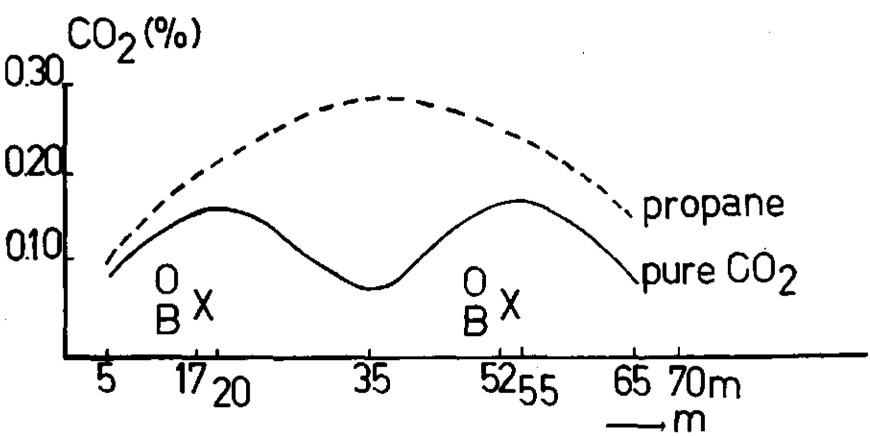

Fig. 3. CO_2 concentrations from pure CO_2 and propane. (0 = gas outlet; B = burner).

From the CO_2-readings it appeared that with propane the highest CO_2 concentrations were found in the middle of the house by accumulation of readily spread gases, while in the case of pure CO_2 the highest values were found near the outlets caused by "poor" diffusion. It is clear, that with pure CO_2 one gets only local distribution, while one covers a much wider field with combustion gases.

CONCENTRATION OF CO_2

The distribution of carbon dioxide will lead to a certain increase in concentration of this gas in the glasshouse. The concentration finally reached is influenced by several factors. We will distinguish factors influencing the height of the concentration and those which govern uniformity.

In the following it is assumed that the ventilators are closed.

Height of concentration. First we mention two factors, involved in Fick's wellknown diffusion law: $dS = Da \frac{dc}{dx} \cdot dt$

a = diffusion area;
D = diffusion constant;
$\frac{dc}{dx}$ = concentration gradient;
dS = diffused quantity;
dt = time.

1. Concentration gradient $\left(\frac{dc}{dx}\right)$. The losses to the outside air are proportional to differences in concentration between in- and outside air. The higher the concentration that is wanted, the more CO_2 will escape into the open.

2. Total diffusion area (a). The losses are also proportional to the total diffusion area in the glasshouse cover. In the Netherlands we observed striking differences between old Dutch light structures and modern houses at this point.

3. Windspeed. The main factor governing the concentration is windspeed. It increases the diffusion rate via the openings in the glasshouse cover. In a modern glasshouse we observed a drop of the CO_2 concentration from 0.18% on a still day to 0.06% on a stormy day with the same CO_2-dosage. Near the coast the effect of wind speed is of course more striking than on the inland.

4. CO_2 source. The choice of the CO_2 source is of less influence on diffusion. When pure CO_2 is employed the gas enters the glasshouse

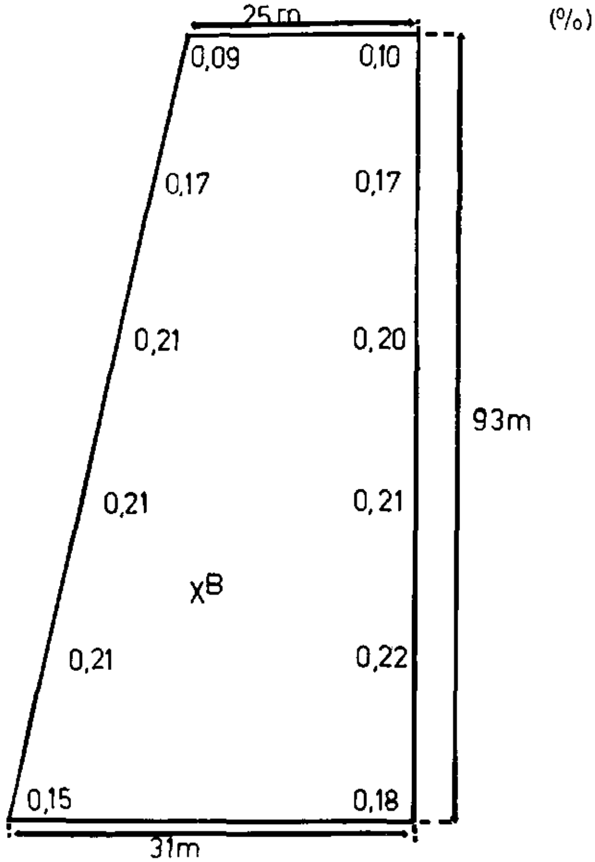

Fig. 4. CO_2 gradient caused by glasshouse shape (in %; B = burner).

at room temperature or below, while CO_2 from combustion gases has a much higher temperature than the surrounding glasshouse air. The pure CO_2 has a tendency to stick near the soil because of "poor" diffusion, and the combustion gases tend to gather near the top of the house because of convection. In the latter case more gas will diffuse to the open. From CO_2 readings it appeared that going from soil level to the top of the glasshouse, the CO_2 concentration increased when combustion gases were used and no fan is applied. With the application of pure CO_2, an inverse gradient was found when the CO_2 was emitted from small plastic tubes near the soil.

5. Fan. When using a fan the glasshouse air is set into motion and diffusion to the open will increase (compare 3, windspeed). In com-

paring the dosing of pure CO_2 via tubes with small openings near the soil with dosing CO_2 from one central opening at a height of two meters, where distribution took place by means of a fan, it appeared that with the use of a fan about 10% more gas was needed to reach the same CO_2 concentration in the house, as with dosing via pipes on the soil.

6. Photosynthesis. The effect of photosynthesis on CO_2 concentration varies strongly with the extent of leaf surface and light intensity (Wittwer and Robb).

7. Watering. It is said that watering by overhead sprinkling will result in a clear drop of the CO_2 concentration.

8. Soil born CO_2. It is known that in cucumber houses large quantities of CO_2 can be released from the masses of fresh organic material used. The amount of CO_2 can be so high that CO_2 enrichment from other sources is superfluous for a long time. With most of the other crops the share of soilborn CO_2 is of little importance upon CO_2 concentration.

Normally the ventilators are closed when extra CO_2 is given. Initial readings showed that a distinct rise of the CO_2 concentration occurs, when CO_2 enrichment takes place when the ventilators are kept open not beyond a width of about 5 cm, and also if the windspeed does not exceed a moderate value (8 m/sec).

Uniformity of concentration. Some factors are known governing uniformity: (1) Shape of the house. If length/width relations are unfavourable concentration may be uneven, as can be seen from Fig. 4. (2) Number of apparatus. The number of apparatus with or without fans, together with their spacial arrangement are also of importance upon uniformity of the CO_2 concentration. The same applies to gas outlets for pure CO_2. (3) Wind-speed. Especially with high windspeeds local uneveness of the CO_2 concentration may occur by inducing an air flow in the glasshouse opposite to the outside wind direction. (4) Height of the crop. The higher the plants, the stronger the influence upon the air movement. This implicates, that with increasing plant lengths the uniformity in CO_2 concentration decreases.

SUMMARY

Three aspects of CO_2 enrichment have been discussed. (1) Apparatus. Demands are made upon combustion gases by man and plant. Causes of incomplete combustion, products of incomplete combustion and damage done on plants. Several types of burners. (2) Distribution of CO_2, by means of a fan or without. The influences of apparatus, glasshouse cover, windspeed, photosynthesis and weather on (3) CO_2 concentrations.

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