APPARATUS FOR CO_2 IN GREENHOUSES

N. VAN BERKEL
Experiment Station for Vegetable and Fruit growing under glass
Naaldwijk, The Netherlands

Summary

Apparatus for CO_2 in greenhouses

The subject to be dealt with shall be discussed along the following line:

Something(sources) is burnt with the aid of some apparatus to CO_2 and water. The CO_2 will be distributed and give rise to a change of the CO_2-concentration.

In more detail the following points will be looked at:

Sources. As such are known: 1° gases CH_4, C_3H_8 and C_4H_{10}; 2° fluids paraffin and ethylalcohol; 3° pure CO_2 and 4° organic material. The possibilities for use depend on the S-content.

Apparatus. Demands made upon combustion gases by man and plant. Causes of uncomplete combustion, products of uncomplete combustion and damage done on plants. Several types of burners.

Distribution of CO_2, by means of a fan or without. The influences of apparatus, glasshouse cover, windspeed, photosynthesis and weather on CO_2-concentration.

Sommaire

Apparatus pour CO_2 en serres

La subject de la conférence sera arrangé d'après la ligne suivante:

Quelque substance (sources)est brûle par un appareil en CO_2 et eau. Le gaz carbonique sera distribué et la concentration du CO_2 changera.

Les parties suivantes seront discutées en détail.

Les sources. On peut distinguer les sources suivantes:
1° les gaz CH_4, C_3H_8, C_4H_{10}; 2° les liquides pétrole et alcohol; 3° le CO_2 pur et 4° la matière organique. Les possibilitiés d'emploi dépendent à la teneur en soufre.

L'appareil. Des demandes mis par l'homme et la plante aux produits de combustion. Des causes de combustion imcomplète. Des produits de combustion incomplète. Du dégât a la plante et plusieurs types de brûleur.

La distribution du CO_2 avec ou sans ventilateur.

La concentration du CO_2. Influence du appareil, de la toiture, vélocité du vent, photosynthèse et l'état de l'atmosphère.

Zusammenfassung

Apparatur für CO_2 in Gewächshäusern

Das Thema worüber es sich handelt, wird der folgenden Linie nach besprochen werden:

Etwas (Quellen) wird verbrannt mittels bestimmte Apparate zu CO_2 und Wasser. Das CO_2 wird verbreitet und bewirkt eine Änderung der CO_2-Konzentration.

Die folgende Punkten werden mehr im Detail betrachtet werden.

Quellen. Als Quellen sind zu erkennen : 1° die Gase CH_4, C_3H_8, und C_4H_{10}; 2° die Flüssigkeiten Petroleum und Aethylalkohol; 3° reines CO_2 und 4° organischer Substanz. Die Möglichkeiten zur Verwendung hängen ab vom Schwefelgehalt.

Apparatur. Ansprüche welche Mensch und Pflanze stellen. Ursachen von unvölliger

Verbrennung. Produkte von unvölliger Verbrennung. Schaden an Pflanzen. Mehrere Brennertypen.
Die Verbreitung des CO_2 mit oder ohne Zuhilfenahme von einem Ventilator.
CO_2-Konzentration; Anteil von Apparatur, Glasdach, Windgeschwindigkeit, Photosynthese, Wetterbedingungen.

1. Introduction

The contents of this lecture will be of a wider scope than the title suggests. Besides the mere apparatus there will be dealt with the sources used for CO_2 enrichment. Further attention will be paid to the distribution of the added CO_2 and finally some factors which govern the CO_2 concentration will be taken into account.

The lecture to be given will take the following line: - Something (sources) is burnt with the aid of some apparatus to CO_2 and water. The CO_2 will be distributed and give rise to a change of the CO_2 concentration.

2. Sources

2.1. Types

We can distinguish several types of source, which are in use for CO_2 enrichment of glasshouse atmospheres. At first we have gases. The most important are natural gas (CH_4) and propane (C_3H_8). Methane is the most important component of natural gas. C_3H_8 and C_4H_{10} (butane) are very important hydrocarbons from refineries. Further we have town gas, a gas with a greatly variable composition because of its fabrication from greatly varying raw materials (Table 1).

Of the fluids, paraffin is used on a large scale in the Netherlands. Ethyl alcohol is a good source but too expensive for practical use.

Pure CO_2 is sold in steel bottles or containers or is available as dry ice.

Finally we have organic material used as rooting medium for cucumbers such as straw bales and beds with a lot of fresh organic substance.

2.2. S-content

The suitability of a source for CO_2 enrichment depends mainly on its sulphur content. In Table 1 are together with figures on carbon contents sulphur contents given of the CO_2 sources in the Netherlands. We learn from this, propane contains less than 0.001% S. Natural gas has a varying content. Gas from the biggest Dutch source at Slochteren contains less than 0.001%. But there are some small sources with very high S-contents (up to 1.9%).

The sulphur content of town gas also varies with the choice of the raw materials.

In paraffin the S %tage also varies to some extent. Mostly the contents are between 0.01 and 0.05%, but sometimes it goes beyond 0.05%. In pure CO_2 the S-content is very low(less than 0.0001%)

2.3. Effect of CO_2

Much research (THOMAS, 1961) has been done on the effect of CO_2 on crops. Above a critical value you may expect injury to plants. One can distinguish between acute and chronic damage. The first arises above a critical CO_2 concentration. The absorbed gas kills the cells by its reducing properties.

When extensive areas are killed, the tissues collapse and dry up leaving a characteristic pattern of interveinal and marginal injury (sulfite injury). Beneath a critical concentration, so little CO_2 is offered, that it will be oxidized into sulfate. This diminishes the toxicity of the sulfite by about 30 times. So rather large quantities can be added without injury on the plants. Finally sulfate injury arises, which is characterized by a white or brownish red turgid surface of the leaves (chronic injury). Above about 0.4 ppm one may expect acute and between 0.1 and 0.4 ppm chronic injury. The occurrence of damage depends further on climate, stage of growth, varity, R.H. Factors that increase opening of the stomata do increase injury, while CO_2 is absorbed via the stomato.

Propane has such a low S-content never to expect any injury.

With natural gases purifying is needed, when gas might be used from sources with a high S-content. With paraffin we have a S-content, where injury may arise. Lowering the S-content is difficult.

When the atmosphere is enriched at about 0.18% CO_2 by burning parrafin with a S-content of 0.05% S, one may expect a CO_2 concentration of about 0.33 ppm. But as a matter of fact under the circumstances of glasshouse climate we see no injury on lettuce, tomatoes and cucumbers, At high CO_2 concentrations (about 0.35%) with a SO^2 figure which is about 0.66 ppm., we have seen some marks of CO_2 injury on the oldest leaves. The sensitivity of a crop plays an important rôle, as will appear from the following:

When tomato plants are grown very weakly during propagation and when they are planted out in an atmosphere where high CO_2 levels occur (about 0.7 ppm), the plant will suffer much injury. Afterwards the plants recover, become hardened, and no further injury will be suffered. If the plants are hardened during propagation, they get little if any injury at such a high CO_2 concentration.

From experience we know paraffin is a good source. More than 50% of the growers make use of paraffin for CO_2 enrichment.

3. Apparatus

3.1. Demands

In many countries demands are made upon (combustion) gases from burners or other sources to protect man against harm from those. The demands are expressed in the so called MAC values (maximum allowable concentrations), at which laborers can work every day during 8 hours, without being afraid for injury on health.

But the demands that plants make, are often different from human demands. This is shown in the following example. The MAC value for CO is 100 ppm (see Table 2). This means that a burner of which the combustion gases are 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 harm on plants. In many cases a plant is far more sensitive than a man is. So the MAC values for CO_2, NO_2,NH_3, O_3, formaldehyde are respectively 5; 5; 50; 0.1 and 5 ppm. But on plants the concentrations for the same substances are 0.2; 20; 10; 0.2 and 0.7 (see Table 2). Plants are very sensitive to ethylene. Already in concentrations of about 0.05 - 0.10 ppm we can get injury on tomatoes.

Not only from a point of health demands are made. Also from a point of explosion there are demands.

Distinct rules are given especially on the equipment for gases, such as propane to protect man from danger of explosion and injury to health, but no distinct rules are given to protect plants from injury.

3.2. Incomplete combustion

Incomplete combustion can have two causes or a combination of both: 1. The burners do not work well because of bad construction, pollution or wrong relation between air and gas supply. 2. Gas from a leakage streams along the outside of the flames of the burners.

3.2.1. Products of incomplete combustion.

The main products of combustion are carbon dioxide and water vapour. But the combustion gases always contain minor quantities of other products such as carbon monoxide, aldehydes, athylene, nitrogen oxides and propane or methane. The better the combustion is, the lower the contents of these minor components will be.

3.2.2. Injury to plants.

Several cases of injury to plants are known. They had always to do with troubles with the burner or were caused by leakages in pipes or connections. The most striking case was with tomatoes. One set of burners, supplied with natural gas, with 18 flames stopped working in the night, while another 21 sets kept working normally. The following morning all plants were heavily injured. The oldest leaves had been burnt, higher leaves were partially damaged (Plate 1).
We must bear in mind that low temperature radiators were installed above the flames. Possibly the combination of bad combustion and radiation gave the heavy injury. In all other cases damage was less and more gradually done. On cucumbers we saw leaves gradually yellowing, to start with the oldest leaves. The same we saw with tomatoes, where also abortion of trusses occured (plate 2). In both cases damage was done by the presence of leakages. Yellowing of leaves and abortion of trusses have also been observed when the burners worked badly. An analysis of gas after incomplete combustion of natural gas revealed that ethylene can be present in a relative high concentration as compared with other harmful components.

3.2.3. How to prevent injury?

1. The total equipment should be installed by reliable firms. The best burners should be mounted and the best materials be employed.

2. Good service must be given. At least once a year the total installation should be tested to be sure all is in good order continually.

3. Stop CO_2 enrichment when one detects some acid smell. Then something is wrong. Call your installer to repair burner or installation. Already when there is very little incomplete combustion one can detect the characteristic smell.

4. Buy only burners which are certificated as reliable. This certificate must be issued preferably by an official bureau. In the Netherlands we hope to make proposals for the foundation of a bureau, where all burners for CO_2 enrichment are tested on the presence and quantity of harmful components in the combustion gases. Only certificated burners will be advised for horticulture. It is not enough to restrict ourselves to the tests carried out on domestic apparatus. Higher requirements are necessary when testing burners for CO_2 enrichment.

3.3. Appliances

3.3.1. For paraffin

There are two different burning principles. The first is known as burning by evaporating. A well-known representative is the hylo (see Plate 3). 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 worked not very reliably. This type is pushed aside more and more by a burner based on another principle: Burning by atomizing; a fan provides a desired air stream. It is automatically controlled and works very well (see Plate 4)

3.3.2. For propane

Many propane appliances are available. Mentioning all has no sense. The combustion of the different propane burners can vary greatly. On this field we feel a strong need for a bureau, which will test all burners. The construction of the appliances is based on one of two principles. On one hand we have the high pressure burners with inlet pressures for propane of 1 or 2 kg/sq. cm. There is a single gas outlet. There is but little chance of pollution. Safeguarding is easy and reliable. An objection is the annoying noise, which accompanies the burning. 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 which easier leads to stopping up. No annoying noise. Many types are known. An example of this type which can also be used for natural gas, is shown on Plate 5.

3.3.3. For pure CO_2

With this appliance you need not to be afraid of getting any damage. The CO_2 contains no contaminations. The CO_2 content is so low, you can neglect it. In most cases pure CO_2 is supplied from bottles or a container to the cultural space, where it flows from very small orifices (with interspaces 30-60 cm) in plastic pipes.

4. Distribution

The CO_2 which is let in the glasshouse must be distributed so uniformly as possible. To achieve this one can:

1) apply a fan,
2) leave the distribution to convection, which will arise by the temperature differences between combustion gases and glasshouse air,
3) leave the distribution to diffusion and accidental air movement caused by insolation, heating pipes and wind speed.

In cases where paraffin is the CO_2 source a fan is always used. With propane in most cases convection is the distribution medium.

From CO_2-readings we learned one fan of good capacity can give a good distribution when the glasshouse area does not exceed about 3000 sq. m. On larger areas more fans are needed for an even distribution. When making use of convection a uniform distribution of CO_2 will be obtained, when appliances are installed at about every 500 sq. m. The distribution from only diffusion is very pour. Only at a restricted area near the CO_2-outlet will you have a clear concentration rise. For this reason a large number of CO_2-outlets is needed per glasshouse. This can be illustrated with Figure 1. In two separate Dutch vinery houses (8 70 sq. m) were installed respectively two propane burners (without fans) and two pure CO_2-outlets at 1/4 and 3/4 of the distance along the length path of the house. From the CO_2-readings we learned with propane the highest CO_2 concentrations were found in the middle of the house by accumulation of readily spread gases, and the highest values near the outlets in case of pure CO_2 by "poor" diffusion. We conclude with pure CO_2 one gets only local distribution and with combustion gases one covers a much wider field.

5. Concentration

The distribution of carbon dioxide will lead to some concentration. The concentration finally reached is inlfuenced by several factors. We will distinguish between factors, which influence the height of the concentration and those which govern the uniformity. In the following it is assumed the ventilators are closed.

5.1. Height of concentration.

First we call two factors involved in FICK's wellknown diffusion law

$$dS = Da \frac{dc}{dx} . dt$$

1. Concentration gradient. The losses to the outside air are proportional to concentration difference between in- and outside air. The higher the concentration is wanted, the more CO_2 will escape to the open.

2. Total diffusion area. 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 an actual case we observed a drop of the CO_2-concentration from 0.18% on a still day to 0.06 on a stormy day at the same CO_2-dosage in a modern house. Near the coast the effect of wind speed is of course more striking than in the inland.

4. CO_2 source. Of less influence on diffusion is the choice of the CO_2 source. When pure CO_2 is employed the gas enters the glasshouse at room temperature or below, while CO_2 from combustion gases have a much higher temperature than the surrounding glasshouse air. The pure CO_2 has tendency to stick near the soil by "poor" diffusion and the combustion gases tend to gather near the top of the house by convection. In the latter case more gas will diffuse to the open, while it takes place at the glasshouse cover. CO_2 readings learned one can find an increasing CO_2 concentration going from glasshouse soil to the top of the house when combustion gases are used. And at little convection an inverse gradient in the gase of pure CO_2 dosed from small plastic tubes near the soil.

5. Fan. When using a fan the glasshouse air is set in motion and diffusion will increase (compare 3. windspeed). A comparison between CO_2 dosing by means of tubes with small openings near the soil and dosing from one central opening at a height of 2 meters, where distribution took place be means of a fan, revealed that with the fan about 10% CO_2 more was needed to get the same CO_2 concentration.

6. Photosynthesis. The effect of photosynthesis on CO_2 concentration varies strongly with the extent of leaf surface and light intensity (see Fig. 2)

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

8. Soil borne CO_2. It is known that in cucumber houses large quantities 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. But normally with most crops the share of soil borne CO_2 is of little interest on CO_2 concentration.

Normally the ventilators are closed when extra CO_2 is given. From initial readings we learned a distinct rise of the CO_2 concentration is reached when CO_2 enrichment takes place when ventilators are kept open not beyond a width of about 5 cm and if windspeed not exceeds a moderate value.

5.2. Uniformity of CO_2 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 Figure 3.
2. Number of appliances. The number of appliances, with or without fans, together with their spatial arrangement have also an important influence on uniformity of the concentration. The same applies to gas outlets for pure CO_2.
3. Wind-speed. Especially when high windspeeds occur it may give rise to local uneveness of the CO_2-concentration by inducing an air flow in the glasshouse opposite to the outside wind direction.
4. Height of the crop. The taller the cultivated plants are, the more they hinder air movement, needed for an even distribution. So the uniformity will be diminished.

References

1. Archives of environmental Health 9, 1964: Treshold limit values for 1964: 545-554.
2. Crocker, W., Zimmerman, P.W. and Hitchcock, A.E.: Contrib. Boyce Thompson Inst. 4, 1932: 177 - 218
3. Thomas, M.D., Air pollution; ed. World Health Organisation Geneva 1961: 233 - 278
4. Wittwer, S.H., and W. Robb, Carbondioxide enrichment of greenhouse atmospheres for food crop production; Economic Botany 18 (1) 1964: 34 - 56

Discussion

G.P. Shipway (U.K.):

A) Could Mr. van Berkel give the reasons why atomising burners are preferred on commercial nurseries to vaporising burners?

B) Has he any experience of the use of the proportionating float control employed on many vaporising burners to regulate the supply of CO_2 with changes in light intensity?

Van Berkel:

A) It appeared atomising burners give a better combustion than vaporising burners. Besides atomising burners can easily be "automised".

B) I have no experience.

G.E. Bowman (U.K.):

In the measurements of CO_2 distribution which CO_2 analyser was used, and where were the sampling points(height) in relation to the propane burners and CO_2 injection tubes?

Van Berkel:

The Riken Gas Analyzer was used. The sampling was done on a height of about 50 cm.

J.V. Lake (U.K.):

Does stirring the air by fans greatly increase the rate of loss of CO_2 to the outside air, as well as increasing the flux towards the leaves? If so, moving the plants through the air would perhaps be an interesting alternative.

Van Berkel:

As I said, introducing a fan gave 10% more loss of CO_2 to the outside air in a vinery house. Stirring the air will thus also increase the flux towards the leaves.

J.V. Lake (U.K.):

In the examples given of spatial variation of CO_2 concentration, what were the numbers and duration of observations on each position? Do the patterns persist for long enough to give corresponding variations in plant growth?

Van Berkel:

The number of observations was above ten and replicated in four houses for each treatment. Each observation took less than a minute. The patterns persisted long enough to expect variation in plant growth, but I did not detect the variation.

Table 1. Some properties of CO_2 sources in the Netherlands

Name	Content (%)	S content (%)
Natural gas	± 80 CH_4	0.0001 - 1.9
propane	± 90 C_3H_8	< 0.001
town gas	4-13 CO_4 14-30 CH_4	0.0001 - > 0.02
paraffin	± 86 C	0.01 - 0.05
pure CO_2	100 CO_2	< 0.0001

Table 2. 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

Plate 1. Injury to tomatoes by incomplete combustion (I) (by the courtesy of ITT, Wageningen).

Plate 2. Injury to tomatoes by incomplete combustion (II).

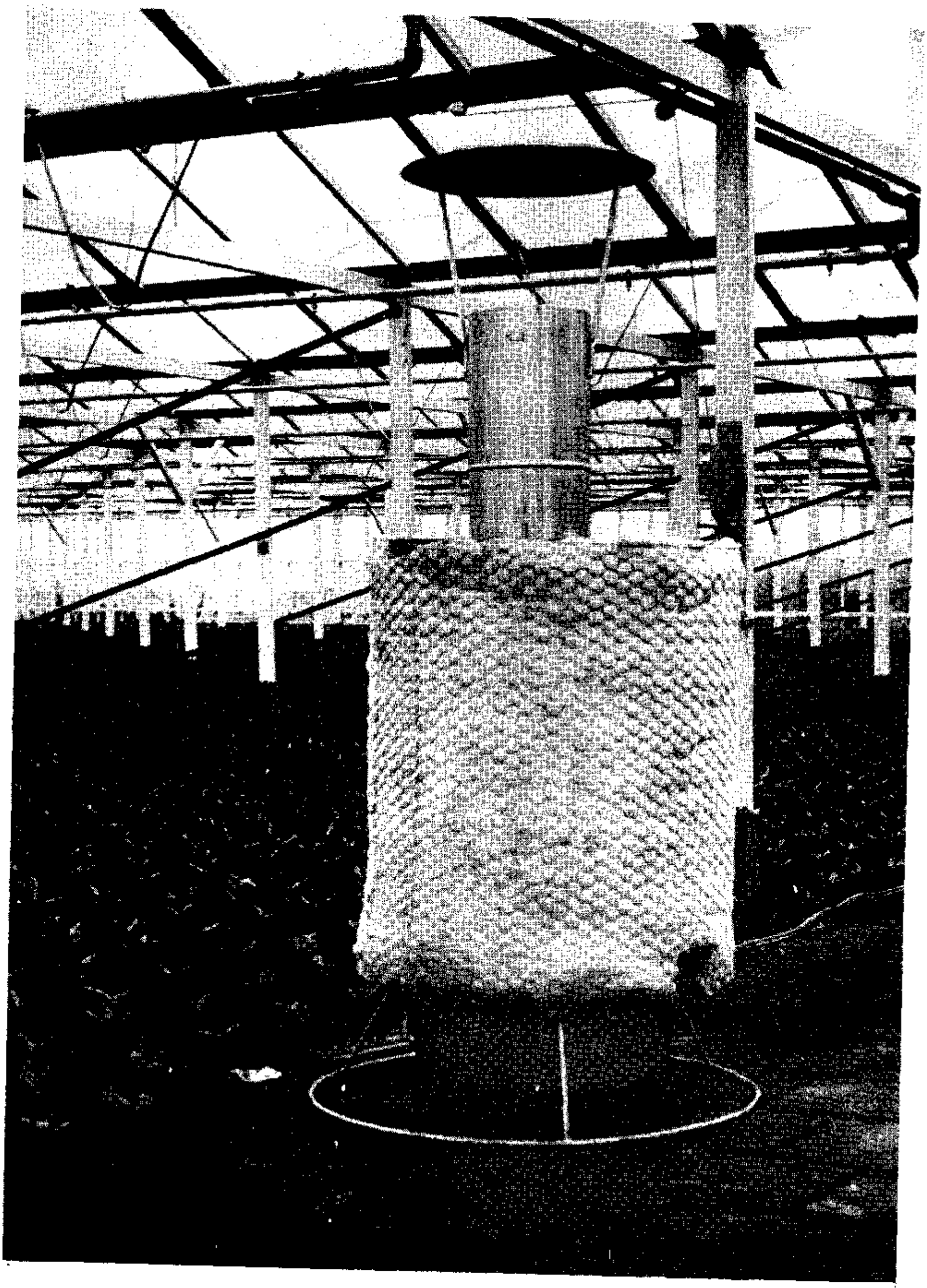

Plate 3. Paraffin evaporating burner.

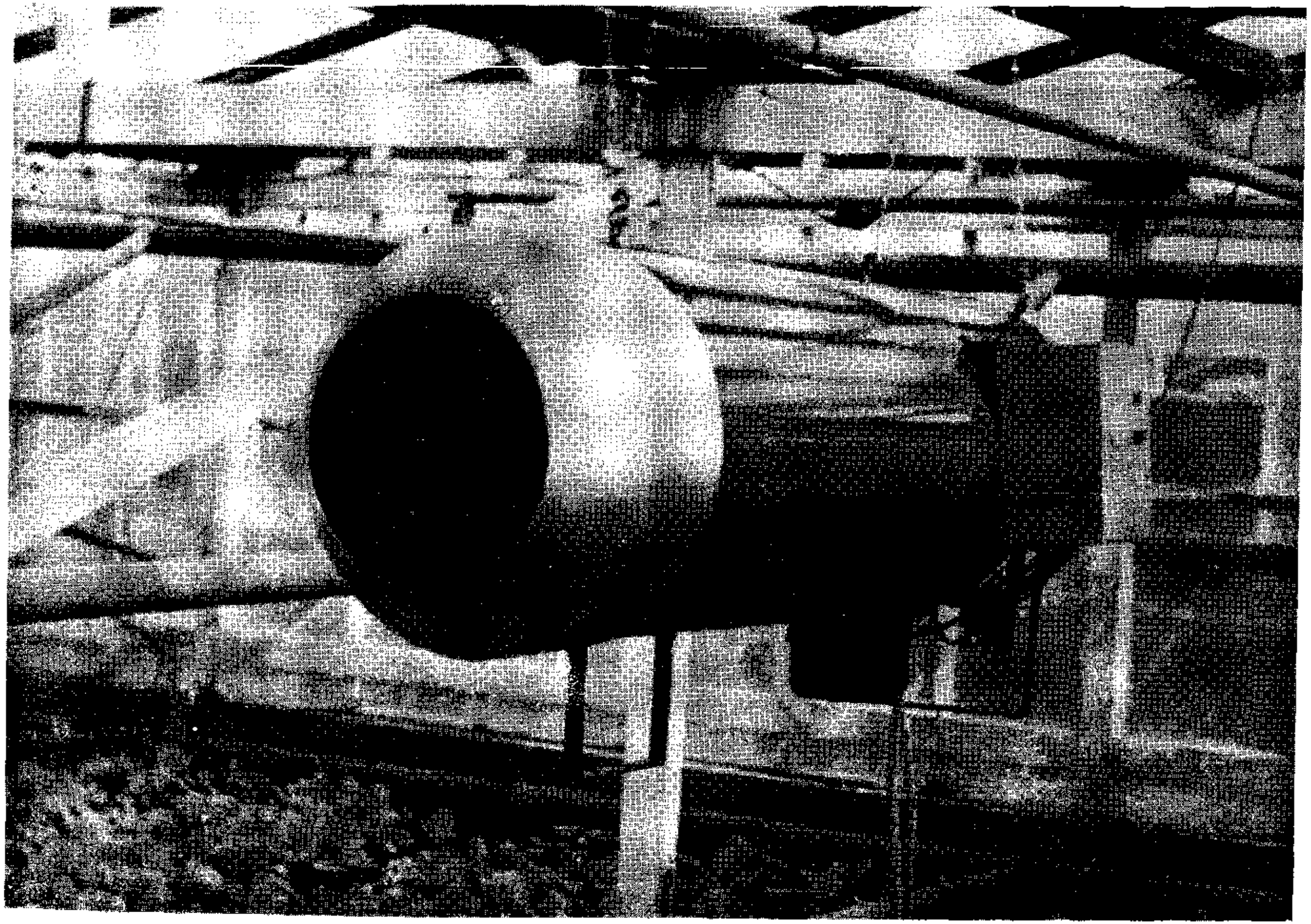

Plate 4. Paraffin atomizing burner.

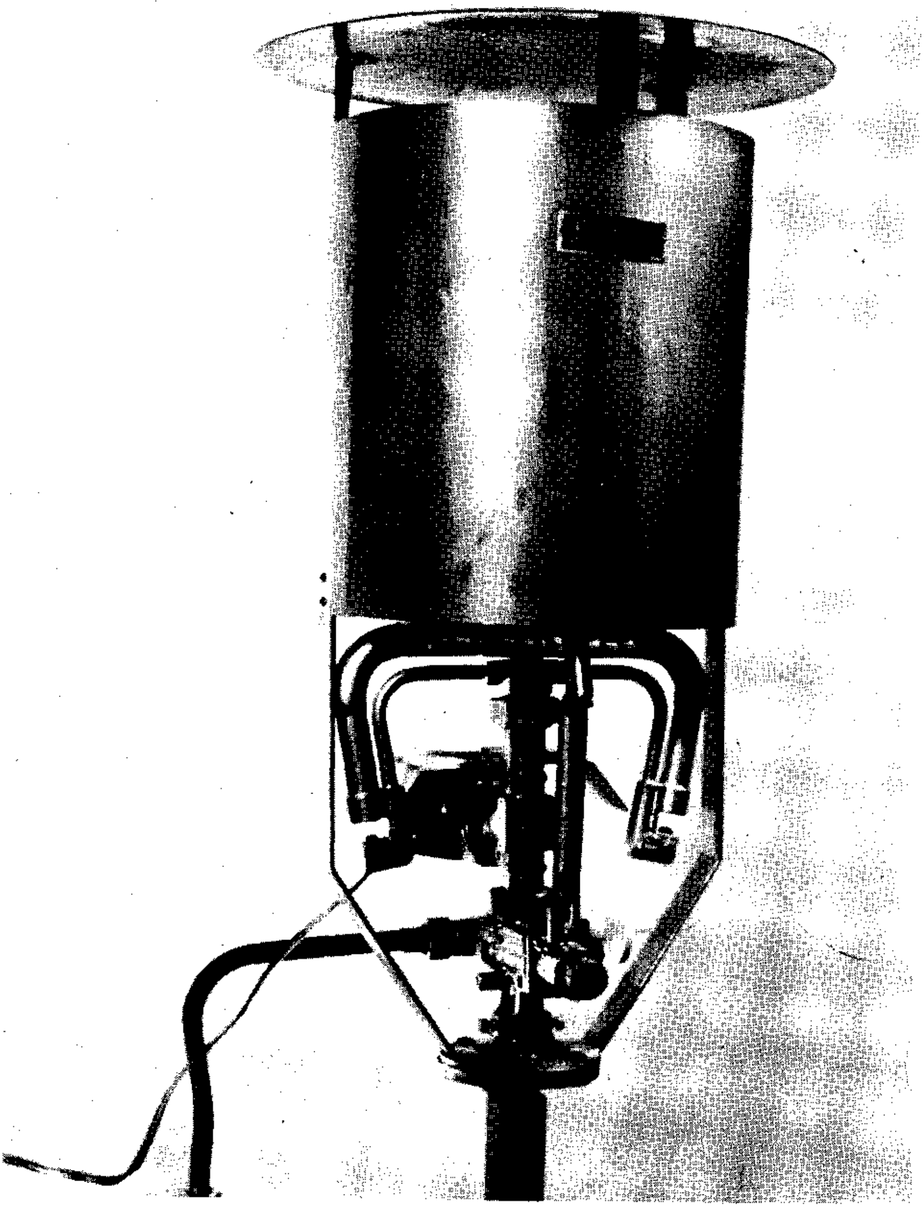

Plate 5. Propane burner.

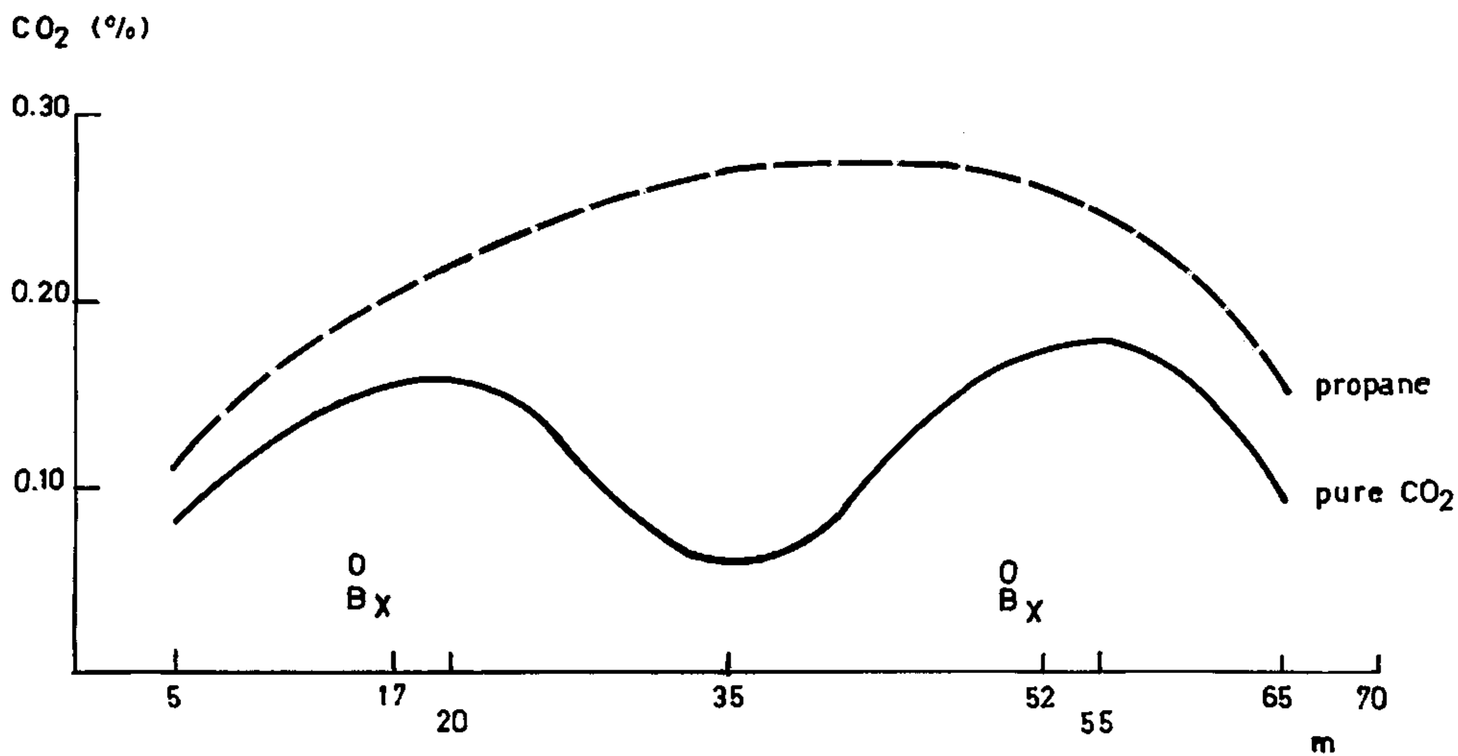

Fig. 1. CO_2 concentrations from pure CO_2 and propane (O = gas outlet; B = burner).

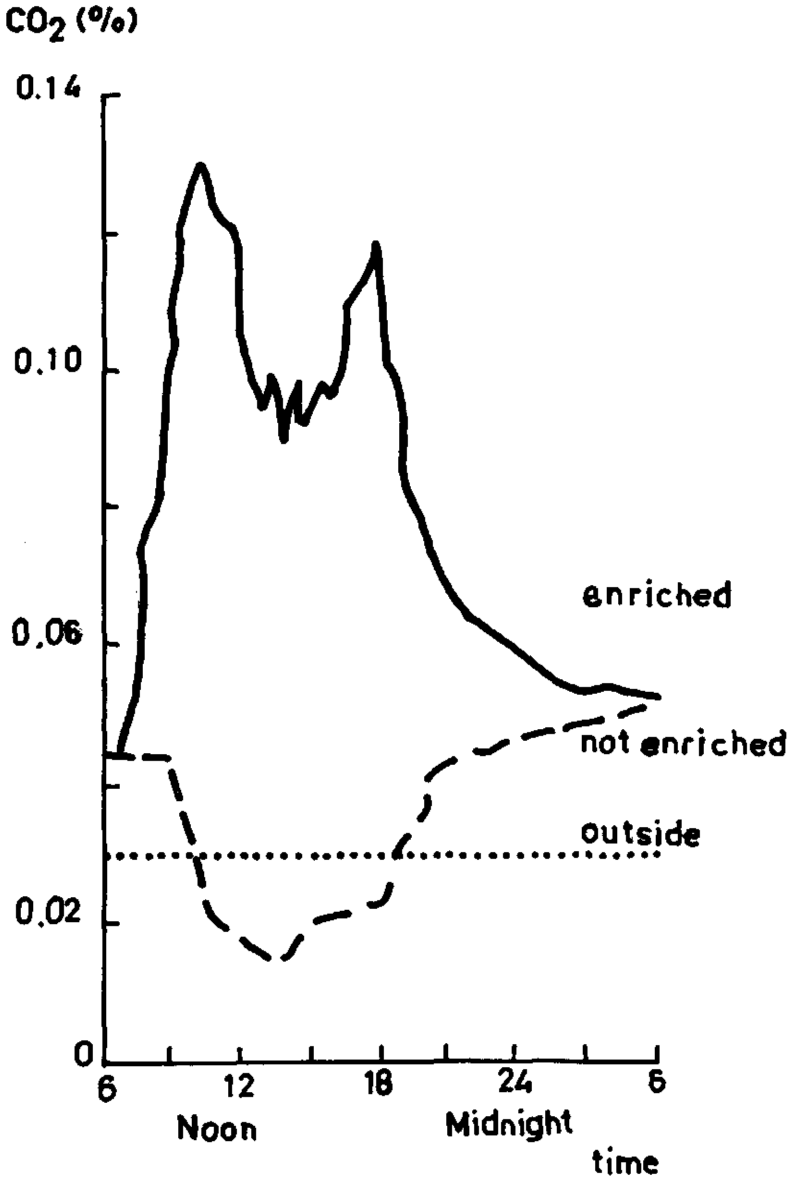

Fig. 2. Effect of photosynthesis on CO_2 concentration in greenhouse (from Wittwer & Robb, 1964).

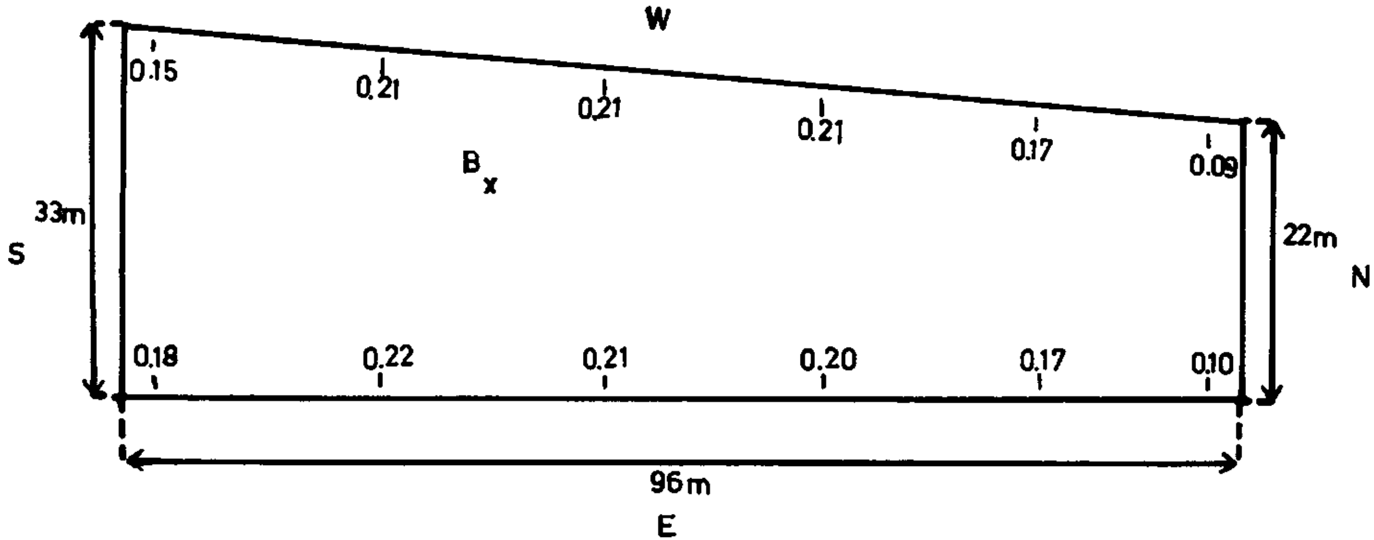

Fig. 3. CO_2 gradient caused by glasshouse shape (in %'s; B = burner; N-W wind, windspeed 8m/sec).

Apparatus for CO_2 in greenhouses

Errata

p.208	39th line	read:	2.3. Effect of SO_2
p.208	40th "	" :	.... the effect of SO_2 on crops
p.208	42nd "	" :	.... above a critical SO_2 concentration
p.209	2nd "	" :	.... so little SO_2 is offered,....
p.209	8th "	" :	.... growth, variety, R.H.....
p.209	14th "	" :	.... by burning paraffin with ....
p.209	15th "	" :	.... may expect a SO_2 concentration ....
p.209	22nd "	" :	.... in an atmosphere where high

SO_2 levels occur (about 0,7 ppm), caused by burning very much paraffin (CO_2 level about 0,35%), the plant will suffer much injury.

p.209	25th line	read:	.... at such a high SO_2 concentration
p.209	41st "	" :	.... values for SO_2, NO_2, NH_3.....
p.210	9th "	" :	.... aldehydes, ethylene, nitrogen, oxides and.....
p.211	20th "	" :	The SO_2 content is so low,.....
p.211	41th "	" :	Dutch vinery houses (8x70 sq.m)were
p.215	5th "	" :	4-13 CO