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Effectivity of an ethylene converter of the heated catalyst type

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EFFECTIVITY OF AN ETHYLENE CONVERTER OF THE HEATED CATALYST TYPE

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Summary

The removal of ethylene (C_2H_4) from a storage room or transport box for agricultural products, in particular flower bulbs, with a converter of the heated catalyst type was investigated. Ethylene is a plant hormoon which affects keepability and quality of agricultural products negative. If it is produced inside a storage room it is usually removed by ventilation (air renewal). For the storage of kiwi's ethylene converters were introduced. The aim of the research project was to investigate the possibilities of these converters for other products compared with ventilation.

A product where the removal of produced ethylene plays an important role is the tulip bulb. Stores and refrigerated transport containers for flower bulbs are ventilated with a relative high ventilation rate. This results in a substantial use of energy needed to change the sucked air from ambient to storage conditions. So the difference in use of energy of both systems was a point of interest.

To assess systems the effectivity of ethylene removal (m^3 eth/m^3 flow) for an ethylene level of 100 ppb is decisive. The effectivity has been measured for three temperatures of the catalyst and for the ethylene converter connected to a room with a high and a low storage temperature.

1. Problem Description

To prevent quality deterioration of metabolic active agricultural product during storage and transport, temperature, humidity and composition of the atmosphere around the product have to be controlled. To realise this for humidity and atmospheric composition there are two phenomena to deal with.
In the first place is that the respiration of the product with the uptake of oxygen and the production of carbondioxide and water. In general the quantity of water produced by the respiration process is small compared to the loss of water caused by evaporation from of the product into the circulating air. So the input of water vapour into the room atmosphere is mainly due to drying of the product or to the inlet of moist air into the storage room.
The second phenomenon is the necessity to remove produced volatiles with harmful side-effects on product quality. This particularly is the case with the gas ethylene (C_2H_4) that activates ripening processes in agricultural products. The sensitivity of agricultural products for ethylene depends on temperature and stage of maturity. In general an ethylene level of 100 ppb [1)] is accepted as upper limit to avoid the initiation of ripening processes.

So to maintain a certain gas composition of the atmosphere inside a storage room or transport box, the control process has to result in the removal of the produced carbon dioxide, the produced ethylene, the water vapour put into the atmosphere and in s upply of the consumed oxygen. This has to be realised at the desired levels of the gascomponents in the composition. For a normal storage or transport, without CA-(controlled atmosphere) or MA-(modified atmosphere) conditions, this means:

O_2 level >= 10 %, CO_2 level <= 1 %, C_2H_4 <= 100 ppb [1)].

Very effective to control the indicated gases is ventilation (air renewal) with ambient air (21 % O_2, 0.05 % CO_2, 5 ppb C_2H_4). In the case of a low oxygen level ventilation can take place with nitrogen from a nitrogen generator mixed with a small quantity of ambient air to supply the oxygen. An alternative is to remove CO_2 and C_2H_4 with a scrubber or converter.

- Aim of the research project:

The aim of this research project is to compare the effectivity of removal of produced ethylene with a converter of the heated catalyst type or by using ventilation. A second comparison to be made is the use of energy in both systems.

There are different means available to remove produced ethylene from a storage room (see table 1 and figure 2). Converters of the heated catalyst type are used in kiwi-storage. For flower bulbs, produced ethylene is usually removed with ventilation (air renewal). Kiwi's produce ethylene at a low rate. Flower bulbs do not produce ethyleen themselves, but bulbs infected by Fusarium do. Infected bulbs become heavy sources of ethylene. So for flower bulbs the possibility to replace ventilation with a converter system depends strongly on the removal capacity of the converter.

[1)] ppb = volume parts per billion = 10^{-9} m^3 eth/m^3

Without adequate counter-measures the ethylene gas spreads through the room and affects the healthy bulbs. Inducing:
- an increase in metabolic activity that slows down the growth of the bulb,
- open sprouts that cause deviations of the normal shape of the leaves later,
- shrivelling of the present rudimentary flower which results in a non flowering plant.

For flower bulbs, in particular tulip bulbs, the presence of infected bulbs can not be avoided. That puts the question to what degree a load of flower bulbs should be protected against infected bulbs. The rule is a limit of 1% infected bulbs. Above that level the storage- or transport-unit has to be emptied and the affected bulbs sorted out. The ethylene production matching the 1% limit is put at 0.38 ml/h.m^3 bulbs. This is based on results of a study [ref/1/].

The presence of ethylene at the low level of 100 ppb is difficult to measure. Up till now only the gaschromatograph is a suitable instrument for this type of measurements. The gaschromatograf needs a skilled operator. So in current practice no ethylene measurements take place and flower bulb rooms and transport vehicles are permanently ventilated with a high ventilation rate to avoid the ethylene problem. This happens during the whole year, even while the sensitivity of the bulbs for ethylene varies during the year.

Table 1 Available systems for ethylene removal.

-	ventilation (air renewal) with air free of ethylene (in clean ambient air the ethylene level is about 5 ppb)
-	gas washer (solution 0.1N $KMnO_4$ + H_2SO_4)
-	oxidation by ozone and oxygen radicals (radiation by UV 185 nm + UV 254 nm; ozone filter in return required)
-	absorber material (like activated aliminum oxide + kaliumpermanganate; Purafil)
-	catalyst at 250 °C - 300 °C

2. Definition Effectivity; mathematical description

The visualization of a storage room or transport box equipped with a scrubber or converter is given in figure 1. The change of the level of a gas component in a room can be described by:

$$V * dC/dt = P - q * \Delta C \tag{1}$$

V	= volume of air the scrubber or converter is acting on	[m^3]
C	= level of the gas component (for the ambience: Ca)	[m^3 gas/m^3]
t	= time	[h]
P	= production of the gas component in the room	[m^3 gas/h]
q	= air flow through the scrubber or the converter system	[m^3/h]
ΔC	= decline of the gas component level in the converter	[m^3 gas/m^3 flow]

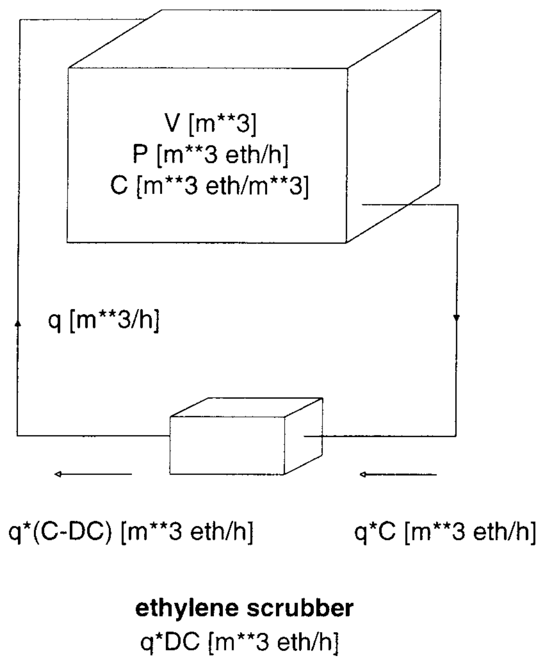

Fig.1 Cold room with ethylene converter (DC = ΔC)

ΔC can be considered as the **effectivity of the converter** and in general will be a function of C. For example substituting ΔC with (C-Ca) in equation (1) gives a solution for C known as the ventilation formula. This formula describes the removal of an undesirable gas component from the room by ventilation with ambient air:

$$C = Co * e^{-q*t/V} + (P/q + Ca) * (1 - e^{-q*t/V}) \quad (2)$$

Co = the level of the gas component at t = 0 h [m^3 gas/m^3]

The formula simplifies for the long term effect (t = ∞) to:

$$C\infty = P/q + Ca \quad [m^3 \text{ gas}/m^3] \quad (3)$$

This leads with P = 0.38 ml eth/h.m^3 bulbs and C∞ = 100 ppb and Ca = 5 ppb to a required ventilation rate for tulip bulbs of q = 4 m^3/h.m^3 bulbs.

- Determining the effectivity of a converter

The effectivity of a scrubber or converter system is measured by following the decline of C caused by the system operation on an airtight vessel after an injection with ethylene gas. A result with different ethylene removal systems is shown in figure 2.

The data are from [ref/2/]. It follows from eq.(1) and P = 0 that
ΔC = - dC/d(q*t/V) [m^3 gas/m^3 flow].
So the effectivity at different C-levels can be found by taking the derivate of curve C against (q*t/V) at those levels.

The decisive effectivity of ethylene removal for agricultural products is **the derivate at C = 100 ppb**.

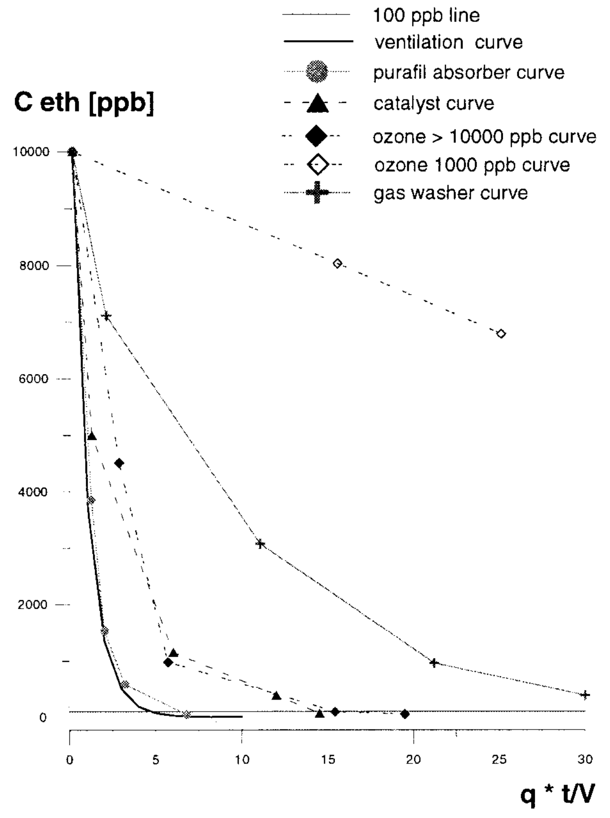

Fig.2 Ethylene level as a function of (q*t/V) for different converter systems

From fôrmer results (figure 2, 1980) ventilation and the use of 'purafil' are the most effective means for removing produced ethylene from a room. Purafil is relative expensive to use while the material is expensive and it can not be regenerated. The catalyst system is the next effective system. Since the measured performance in 1980 new catalyst systems have been introduced into the market, reason to update the available data.

3. Description of the Ethylene Converter

Name : Deoxyl 150
Manufacturer: Isolcell Italia SpA, Laives (BZ), Italy
Rated airflow: 150 m^3/h
Rated energy consumption: 1,6 kW

Reaction process: $C_2H_4 + 3\ O_2 \rightarrow 2\ CO_2 + 2\ H_2O$
The conversion efficiency of this process is enhanced by the presence of a catalytic material heated to a temperature in the range of 250 °C - 300 °C.
The reaction box is mounted between two boxes with material with a large heat capacity and restricted resistance for airflow (see figure 3). The box material in the upstream cools down to the temperature of the air coming from the cold room. The box material in the downstream cools the heated air from the reaction box before it is returned to the cold room. The direction of the airflow through the boxes is reversed at regular intervals.

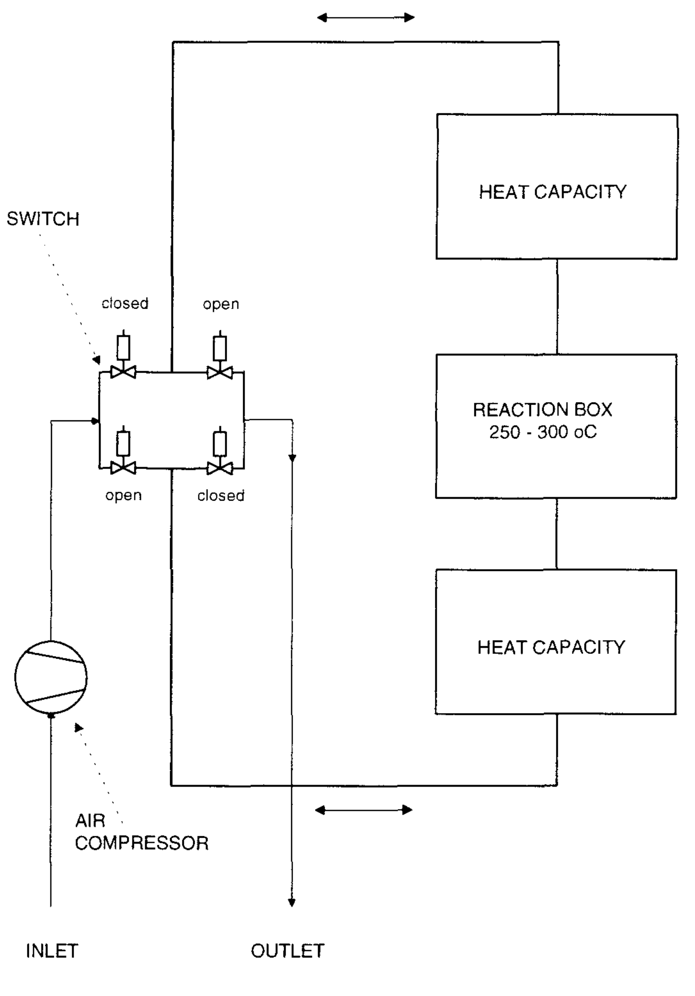

Fig.3 Schematic picture of the ethylene converter of the heated catalyst type

4. The Setup of the Experiments

The ethylene converter, described in CHAPTER 3, was connected to a small cold room of the ATO research institute. Flexible tubes of 5.8 cm diameter and about 2.5 m length were used for this purpose. The suction inlet was placed in the middle of the room and the delivery outlet near the wall of the room in the return flow of the circulating air to the heat exchanger. Air is fractionally heavier than ethylene. The difference however is too small to impaire mixing of the two gases. The circulation fans in the room were kept running during experiments to ensure a uniform mixture.

Density of ethylene at 15 °C and atmospheric pressure: 1.194 kg/m^3
Density of air at 15 °C and atmospheric pressure: 1.22 kg/m^3

The cold room has a glycol cooler and an electrical heater. The glycol refrigeration system has the advantage that short term temperature fluctuations in the cold rooms are small; within 1.2 °C.

The room has an internal volume of 18 m^3.
The flow rate of the air through the scrubber under the experimental conditions was measured with a volumetric flow meter (ACIN Flow Finder model 153).
Result: 110 m^3/h and a (q/V)-factor for these experiments of 110/(18*60) = 0.102 min^{-1}.

Provisions were made to secure the airtightness of the room by blocking the vent openings and openings around the closed door, etc. The airtightness of the room has been tested, following the method and rules for CA (controlled atmosphere) stores. The prepared room just reached ULO (ultra low oxygen) conditions.

The converter was connected to a 380 V/50 Hz, 3 phase, electric supply. A kWh-meter was included in the circuit.
To operate the switch of the converter a connection with a source of compressed air (4-6 bar, >= 30 l/h) is essential.

To establish the heat load for the room (extra energy to be used for cooling) due to the heating of the air circulating through the converter, the temperatures of intake and delivery air of the converter were recorded.

The temperature of the catalyst is displayed on the digital display of the thermostat. Experiments were carried out with three settings of the catalyst temperature in the range 250 °C - 300 °C. The three settings are indicated by low, middle and high range (see annex with experimental results). The catalyst is heated with a two step heater and completes a range of temperatures with a reach of about 12 °C up and down during operation. The indicated temperatures during operation stayed below the thermostat settings for about 10 °C.

Next to changes in the catalyst temperature, two levels of room temperature were introduced in the experiments, namely 18 oC and 5 oC. Thus the series of experiments was based on 3 * 2 variables and a repetition of the measurements. That makes a total of 12 experiments. However, the available converter gave some troubles by making unexpected stops. Then it indicated a too low catalyst temperature. That indication was faulty for the too low catalyst temperature could not be observed. The real reason for the call upon the low temperature protection of the converter has not been solved. While the right result of an experiment, being a curve of the ethylene level in the room against time, depends on a continuous operation of the converter some experimental results could not be used. So experiments had to be repeated more than once. In the end a total of nine results remained of value for the assessment of the converter performance.

By taking air samples from the room at regular intervals the changing ethyleen level inside the room was measured. A sampler system with 6 compartments served for this purpose. The samples were analysed afterwards by a gaschromatograf.

The converter was started about two hours before the start of an experiment to heat the catalyst material sufficiently. The experiment itself starts with the injection of ethylene into the room and taking the first air sample after 10 minutes (experimental time zero). The ethylene injection is performed by hand by opening a valve connected to a bottle of compressed (industrial pure) ethylene for some seconds. It means that experiments start with different ethylene levels at time zero. After some practice the starting level can be held near 10000 ppb. This manner of working makes no difference for the main result of the experiment, namely the assessment of the derivate to the curve C_{eth} = function of (qt/V) at ethylene level = 100 ppb. To present the results in a uniform way the timescale of the measurements has been shifted to match 10000 ppb at zero time. The procedure is visible by looking at the time of the second entry of a series in the annex. If this time does not correspond with the intervals used in the series a shifting took place. The shift time is derived by interpolation or extrapolation of the $C_{eth}(t)$ data, using the best exponential fit of the data. This does not implicate that for the available ethylene converter the function $C_{eth}(t)$ is an exponential function in reality. Only that the shape is similar to such a function for high ethylene values. For the further presentation the measured values are used.

5. Results of Measurements

Figures 4, 5 and 6 show graphs of the results. Table 2 shows the values of the effectivity of the converter on the ethylene level of 100 ppb. For comparison the value for ventilation with ambient air is 95 * 10^{-9} m^3 eth/m^3 flow.

It is clear from table 2 that the performance of this ethylene converter can easily match the performance of ventilation for a room with a storage temperature (= air intake temperature) of 18 °C. In that case the catalyst operates better in the low side of the temperature range of 250 - 300 °C than in the high side. If the room temperature is 5 °C the performance of the ethylene converter is much worse but slightly better than the catalyst converter looked at in 1980 [ref/2/]. At the low room temperature about 1/4 - 1/3 of the capacity of ventilation remains. It is logical that an ethylene converter is designed for use with relative high storage temperatures. The sensitivity of agricultural products for ethylene diminishes strongly with temperature and even so the ethylene production. In the case of flower bulbs the production comes from a different source but also there the production diminishes with temperature. The decline of ethylene production from 0.38 ml eth/h.m^3 at or about 15 °C to 0.1 ml eth/h.m^3 at about 8 - 10 °C (1 % protection level) means also a ratio of about 4 to 1. From this follows that the converter has to be operated with the same flow rate at high and low storage temperatures. In the ventilation system the rate can be lowered for low storage temperatures.

Table 2 Effectivity of the converter at ethylene level 100 ppb.

Catalyst temperature in °C	Room temperature in °C	Effectivity at 100 ppb in 10^{-9} m^3 eth/m^3 flow
242 - 254	18	114
242 - 254	18	123
261 - 274	18	77
261 - 274	18	81
279 - 292	18	78
281 - 293	18	71
245 - 254	5	22
269 - 279	5	26
270 - 285	5	35

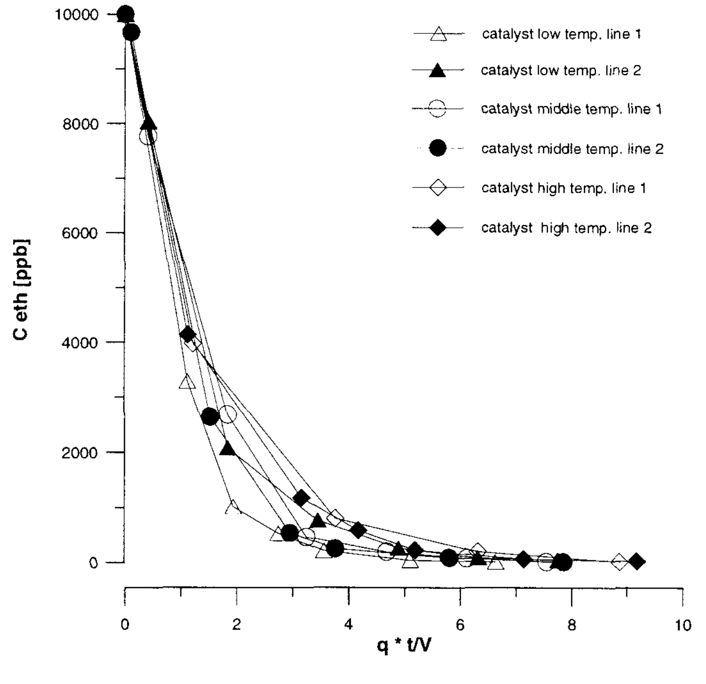

Fig.4 Results of measurements $C_{eth} = f(q*t/V)$ for the room at 18 °C

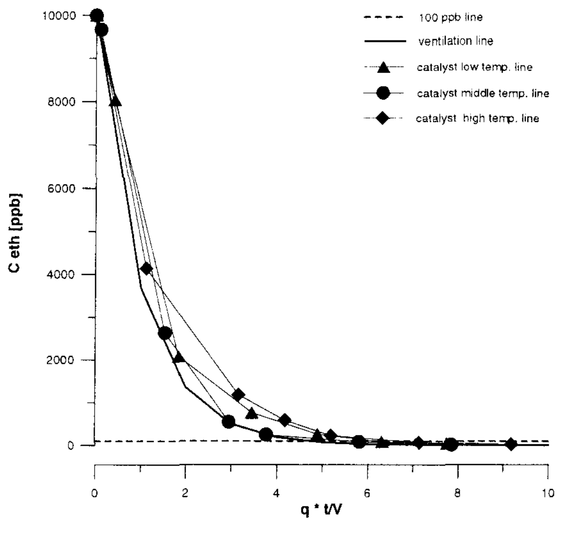

Fig.5 Comparison of the best results of fig. 5 with the result of ventilation

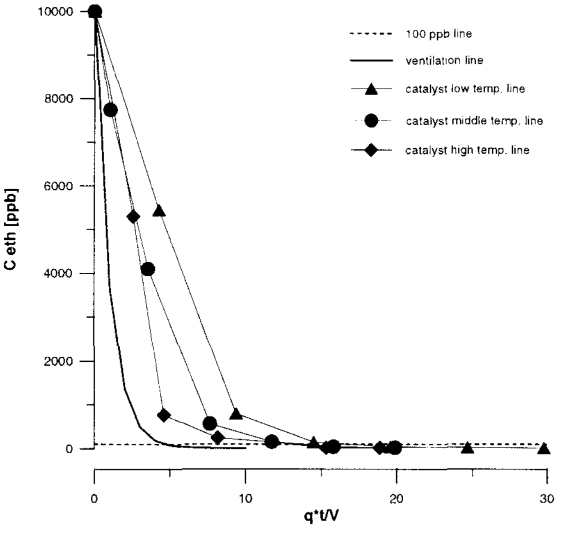

Fig.6 Results of measurements $C_{eth} = f(q*t/V)$ for the room at 5 ˚C

There is no obvious reason for the diminished performance of the ethylene converter when connected to a low temperature room. The indicated temperatures of the catalyst are the same for both series of experiments. Compare the catalyst temperatures in the tables of the ANNEX, "experiment 1-6" and "experiment 7-9". The principal distinction is another difference in temperature between air and catalyst material in the reaction compartment.

The heating of air by the converter from intake to delivery is 4 - 5 °C for the room at 18 °C and about 11 °C for the room at 5 °C.
The electric energy consumption of the converter ranges from 0.85 to 1.13 kWh per hour [kW] in the experiments.

6. Comparison between ventilation and the use of the ethylene converter

Flower bulbs are kept at different temperature levels for certain periods to prepare them for flowering at the desired time and place (climate). The temperature levels range with some exceptions from 2 °C - 20 °C. The different temperature levels have a prescribed ventilation rate. The ventilation rate steps up from 15 to 20 to 60 to about 100 $m^3/h.m^3$ bulbs going from the low temperature to the high temperature. Thus the standards used for land based installations are much higher than for transports. For the latter 4 $m^3/h.m^3$ bulbs at 18 - 20 °C is normal. The significance of this is that a considerable higher protection level is maintained for storage compared with transport; 15 - 25 % against 1 %. This complicates the possible replacement of ventilation by an ethylene converter while the available converters are limited in size. The largest manufactured Deoxyl ethylene converter has a flow rate of 750 m^3/h. This matches about 7.5 m^3 of marketable tulip bulbs or 12.5 m^3 of seed bulbs.

Tabel 3 Estimation of the use of electric energy for removal of ethylene. The ventilation share is based on the mean enthalpy of the ambient air in August, September, namely 25 kJ/kg [ref/3/, page 478].

Temperature →	2 - 5 °C		18 - 20 °C	
	ventilation	eth. converter	ventilation	eth. converter
flow rate	20 $m^3/h.m^3$ bulbs	80 $m^3/h.m^3$ bulbs	80 $m^3/h.m^3$ bulbs	80 $m^3/h.m^3$ bulbs
temperature and enthalpy difference to cool or heat [1].	depends on ambient temp. +330 $kJ/h.m^3$ bulbs	11 °C +1070 $kJ/h.m^3$ bulbs	depends on ambient temp. -1730 $kJ/h.m^3$ bulbs	5 °C +470 $kJ/h.m^3$
use electric energy	none	1 kW for 110 m^3/h; rated 6 kW for 750 m^3/h	none	1 kW for 110 m^3/h; rated 6 kW for 750 m^3/h
Estimation (total)	1.5 kWh/m^3 bulbs per 24 h	20 kWh/m^3 bulbs per 24 h ([2] 15.4 kWh/m^3)	11.5 kWh/m^3 bulbs per 24 h	17.4 kWh/m^3 bulbs per 24 h ([2] 15.4 kWh/m^3)

1) + = cooling; - = heating; conversion cold/electr. = 5.4 MJ/kWh; conversion heat/electr. = 3.6 MJ/kWh (electrical heating).
2) use of energy by the converter apparatus.

From table 3 it becomes clear that the energy used by the ethylene converter itself for heating and air circulation makes the converter not a serious competitor to replace ventilation for the sake of saving energy. This is true for ventilation systems that use the pressure difference over the heat exchanger(s) and the load, caused by the air circulation fans of the room, as their driving force. If extra fans are installed to ventilate flower bulb rooms than the picture changes.

7. Conclusions

- The ethylene converter with catalyst removes ethylene from a storage room.

- The effectivity of ethylene removal (m^3 eth/m^3 flow) at the for agricultural commodities important ethylene level of 100 ppb is comparable to that of ventilation when the converter operates on a high temperature storage room (18 °C).

- The effectivity was found worse when the converter operated on a low temperature storage room (5 °C). Then 1/4 - 1/3 of the effectivity of ventilation remained. The result means that for low storage temperatures a converter must be chosen with a 3 to 4 times higher flow rate than the flow rate in use for ventilation.

- The ethylene converter removes ethylene better when the catalyst temperature is held at the low side of the range used in the experiments, namely 250 - 300 °C.

- The use of this ethylene converter with flower bulbs in stead of ventilation, for the sake of saving energy, is only an option for rooms where special ventilation fans are installed and the fans for air circulation are not used for that purpose.

- In flower bulb storage the use of very high ventilation rates is common practice. This complicates the replacement of ventilation with ethylene converters while the maximum flow rate of available ethylene converters is probably too limited.

- The application of catalyst ethylene converters during transports of flower bulbs in refrigerated containers has better prospects. The usual required transport temperature is in the range of 15 - 25 °C where the effectivity of the ethylene converter is very good. Moreover the applied ventilation rate is substantial lower than for land based storage rooms and still high for application with other agricultural commodities. The latter widens the field of transport applications. For this field of applications the size of the apparatus is of special importance to avoid occupation of valuable loading space.

8. REFERENCES

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/2/ J.W. Rudolphij and H.A.M. Boerrigter, Scrubbers for ethylene, methods and effectivity (Dutch), Koeltechniek 73 (1980) nr. 8, p173-178.
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Publisher: P.C. Noordervliet B.V., P.O.Box 268, 3700 AG Zeist, the Netherlands.

ANNEX: Results of measurements

Room temperature: 18.3 ˚C Room humidity : 52 %	Temp. setting catalyst min. 250 ˚C, max. 265 ˚C	Use of electric energy 1.13 kWh per hour [kW]
Catalyst temp.: low range	Observed temp. range min. 242 ˚C, max. 254 ˚C	Temperature difference intake - delivery: 4.3 ˚C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
11	1.12	3290
19	1.94	1020
27	2.75	530
35	3.57	215
50	5.10	40
65	6.63	10

Experiment 1: Catalyst temp.: low range ; Room temp.: 18 ˚C
Effectivity 100 ppb : (215-40)/1.53 = 114 * 10^{-9} m^3eth/m^3 flow

Room temperature: 18.5 ˚C Room humidity : 52 %	Temp. setting catalyst min. 250 ˚C, max. 265 ˚C	Use of electric energy 1.15 kWh per hour [kW]
Catalyst temp.: low range	Observed temp. range min. 242 ˚C, max. 254 ˚C	Temperature difference intake - delivery: 4.3 ˚C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
4	0.41	8040
18	1.84	2080
34	3.46	765
48	4.90	260
62	6.32	85
76	7.75	45

Experiment 2: Catalyst temp.: low range ; Room temp.: 18 ˚C
Effectivity 100 ppb : (260-85)/1.42 = 123 * 10^{-9} m^3eth/m^3 flow

Room temperature: 18.1 ˚C Room humidity : 52 %	Temp. setting catalyst min. 270 ˚C, max. 285 ˚C	Use of electric energy 1.02 kWh per hour [kW]
Catalyst temp.: middle range	Observed temp. range min. 261 ˚C, max. 274 ˚C	Temperature difference intake - delivery: 5.2 ˚C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
4	0.41	7770
18	1.84	2685
32	3.26	460
46	4.69	190
60	6.12	80
74	7.55	15

Experiment 3: Catalyst temp.: middle range ; Room temp.: 18 ˚C
Effectivity 100 ppb : (190-80)/1.43 = 77 * 10^{-9} m^3eth/m^3 flow

Room temperature: 18.2 ˚C Room humidity : 52 %	Temp. setting catalyst min. 270 ˚C, max. 285 ˚C	Use of electric energy 1.02 kWh per hour [kW]
Catalyst temp.: middle range	Observed temp. range min. 261 ˚C, max. 274 ˚C	Temperature difference intake - delivery: 5.2 ˚C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
1	0.10	9675
15	1.53	2640
29	2.96	540
37	3.77	250
57	5.81	85
77	7.85	10

Experiment 4: Catalyst temp.: middle range ; Room temp.: 18 ˚C
Effectivity 100 ppb : (250-85)/2.04 = 81 * 10^{-9} m^3eth/m^3 flow

Room temperature: 18.3 °C Room humidity : 52 %	Temp. setting catalyst min. 285 °C, max. 299 °C	Use of electric energy 0.88 kWh per hour [kW]
Catalyst temp. : high range	Observed temp. range min. 279 °C, max. 292 °C	Temperature difference intake - delivery: 4.4 °C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
11	1.12	4140
31	3.16	1180
41	4.18	585
51	5.20	225
71	7.24	65
91	9.28	23

Experiment 5: Catalyst temp.: high range ; Room temp.: 18 °C
Effectivity 100 ppb : (225-65)/2.04 = 78 * 10^{-9} m^3eth/m^3 flow

Room temperature: 18.2 °C Room humidity : 52 %	Temp. setting catalyst min. 289 °C, max. 299 °C	Use of electric energy 0.89 kWh per hour [kW]
Catalyst temp. : high range	Observed temp. range min. 281 °C, max. 293 °C	Temperature difference intake - delivery: 4.4 °C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
12	1.22	3980
37	3.77	805
62	6.32	195
87	8.87	15
112	11.42	11
137	13.97	10

Experiment 6: Catalyst temp.: high range ; Room temp.: 18 °C
Effectivity 100 ppb : (195-15)/2.55 = 71 * 10^{-9} m^3eth/m^3 flow

Room temperature: 5.2 °C Room humidity : 75 %	Temp. setting catalyst min. 250 °C, max. 265 °C	Use of electric energy 0.85 kWh per hour [kW]
Catalyst temp.: low range	Observed temp. range min. 245 °C, max. 254 °C	Temperature difference intake - delivery: 11.3 °C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
42	4.28	5450
92	9.38	790
142	14.48	147
192	19.58	35
242	24.68	26
292	29.78	15

Experiment 7: Catalyst temp.: low range ; Room temp.: 5 °C
Effectivity 100 ppb : (147-35)/5.1 = 22 * 10^{-9} m^3eth/m^3 flow

Room temperature: 5.5 °C Room humidity : 72 %	Temp. setting catalyst min. 275 °C, max. 285 °C	Use of electric energy 0.93 kWh per hour [kW]
Catalyst temp.: middle range	Observed temp. range min. 269 °C, max. 279 °C	Temperature difference intake - delivery: 11.1 °C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
10	1.02	7740
35	3.57	4090
75	7.65	560
115	11.73	150
155	15.81	45
195	19.89	15

Experiment 8: Catalyst temp.: middle range ; Room temp.: 5 °C
Effectivity 100 ppb : (150-45)/4.08 = 26 * 10^{-9} m^3eth/m^3 flow

Room temperature: 5.5 ˚C Room humidity : 72 %	Temp. setting catalyst min. 285 ˚C, max. 299 ˚C	Use of electric energy 1.06 kWh per hour [kW]
Catalyst temp.: high range	Observed temp. range min. 270 ˚C, max. 285 ˚C	Temperature difference intake - delivery: 11.7 ˚C
Time [minutes]	qt/V	ethylene level [ppb]
0	0	10000
25	2.55	5300
45	4.59	761
80	8.16	240
115	11.73	145
150	15.30	17
185	18.87	15

Experiment 9: Catalyst temp.: high range ; Room temp.: 5 ˚C
Effectivity 100 ppb : (145-17)/3.57 = 35 * 10^{-9} m^3eth/m^3 flow