PRACTICAL APPROACHES TO PURGING GRAIN STORAGES WITH CARBON DIOXIDE IN AUSTRALIA

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ABSTRACT

Carbon dioxide used to produce modified atmospheres containing greater than or equal to 70% CO_2 for disinfesting stored grain in Australia is manufactured and delivered to country storage terminals as a pressurised bulk liquid by road tankers for distances of up to several hundred km. On-site purging costs and delivery costs can constitute a substantial part of the total CO_2 purging cost. For instance, when purging fourteen 2000 tonne capacity vertical steel bins the purging cost can rise by about 8.5 cents/t of wheat if the purge rate is reduced from 3 to 1 t CO_2/h due to higher on-site costs. Similarly it will rise by about 15 cents/t of wheat when purging a 28,000 t capacity horizontal bin due to larger amounts of CO_2 required for this type storage.

The additional tanker delivery cost, excluding on-site tanker charges, can add about 8.5 cents/t of wheat to the cost of purging the vertical bin facility when it is 100 km away while the difference for the horizontal bin is about 13 cents/t of wheat. On-site costs can be reduced appreciably by the selection of adequately sized equipment for the site to allow high CO_2 purge rates. Details are given of a low pressure distribution circuit and bin piping arrangement for a 28,000 t multi-bin terminal which will allow several bins to be purged simultaneously at a total CO_2 rate in excess of 3t/h. The liquid CO_2 can be conveniently vapourised at site and the gas heated to wheat temperatures with a transportable 3t/h nominal capacity forced draught vapouriser with electric superheater. Total power consumption for an output of 3.5t/h is 47 kW compared to about 340 kW for all-electric vapourisation. Air can be drawn in and mixed with the CO_2 stream to form mixtures with an air content ranging from zero to greater than 30%.

INTRODUCTION

Full scale trials involving the use of modified atmospheres containing CO_2 to disinfest stored grain in Australia commenced with tests in a 7000-t vertical steel bin at Bodertown, South Australia, in 1977. This research was followed with other trials involving vertical bins of 1500 to 3000-t capacity in Victoria and Queensland and in horizontal shed-type bins of 16,400 t and 25,000 t capacity in New South Wales and Western Australia, respectively. Carbon dioxide has been used commercially on a small scale for grain disinfestation during the past few years in Queensland and Victoria (Banks and Annis, 1980).

A substantial part of the cost of purging grain storages which are remote from the CO_2 production plants is the cost of the liquid CO_2 delivery and the on-site purging cost. These costs can be reduced by using a suitable high capacity CO_2 vapouriser and adequately sized bin CO_2 injection and venting arrangements and, for sites containing clusters of smaller bins, by connecting these to a properly sized CO_2 distribution network to allow a number of bins to be purged simultaneously. The possibility that small quantities of other fumigants may be required to be added to a CO_2 or CO_2-air mixture before it enters a bin should be considered when designing CO_2 purging systems (Williams, 1983).

Bulk liquid CO_2 is transported to the wheat storage sites in conventionally insulated road tankers generally having a net capacity of 20 tonnes. The total road weight of the tank and the prime mover is around 38 t which is the maximum allowed by most State authorities. These tankers regularly move 20 t lots of CO_2 across and around the Australian continent for distances of up to 3000 km. The total cost of a complete rig is in the vicinity of $220,000 and thus the cost of delivery including the on-site tanker costs can represent up to 50% of the total purging cost.

The exposure periods and CO_2 concentration levels in air for modified atmospheres currently being used in Australia to disinfest stored grain and which are believed to give complete insect mortality are as follows: 10 days or longer (in practice 14 days) with initial CO_2 levels greater than or equal to 70% and final levels greater than 35% for grain with a moisture content of less than 12% and at a temperature of greater than or equal to 20°C (Banks, 1979). Since the treatment is generally carried out during or immediately following the harvest period in summer or early autumn most grain temperatures in sealed non-aerated storages are in excess of this temperature.

Before purging with CO_2 it is essential that wheat bins and any interconnecting ductwork and fans be sealed to an adequate standard of gastightness to ensure that the CO_2 concentration does not fall below 35% within the 14 day treatment period (Banks and Annis, 1977). For structures of 300–10,000-t capacity a minimum decay time, depending on size, of 5 minutes for an applied pressure drop of either 2500 to 1500 Pa, 1500 to 750 Pa or 500 to 250 Pa in a full storage is considered a satisfactory gastight standard (Banks and Annis, 1980). The CO_2 is applied in a one-shot operation without any subsequent make-up and the atmosphere within the bin allowed to degrade (due to leaks) during the 14 day treatment period. In order to maintain reasonably uniform concentrations throughout the bin and also to ensure that the CO_2 concentration near the apex is maintained at the desired level a small stream of CO_2 rich gas is recycled from the base of the bin to the apex (Wilson et al., 1980).

It has been found during full scale trials and commercial purging operations in Australia that the above criteria are met when using 1 t

CO_2/1000 t of wheat in vertical steel bins with 5% headspace and when using 2 t CO_2/1000 t of wheat in horizontal shed-type bins with 40 to 45% headspace (Banks et al, 1980). The density of CO_2 gas is about 50% greater than that of air at ambient temperatures and when it is injected into the base of a vertical bin it floods rapidly across the bin floor and then rises through the wheat mass, displacing the air present with a minumum of mixing. A single injection point is thought to be satisfactory for cylindrical vertical bins of up to 10,000 to capacity. In large horizontal bins the CO_2 can be readily distributed throughout the bin via the existing below floor aeration ducts or through temporary perforated aeration ducting installed on the floor.

The application of CO_2 to a wheat storage bin involves some type of structural addition and/or modifications to the bin either in a minor or of a more substantial nature to allow the gas to be injected and distributed within the bin and to allow the displaced air and exhaust CO_2 to escape from the bin without over pressurising and damaging the bin fabric. These changes or additions are generally made with medium to long term use in mind. The system finally chosen should provide the optimum CO_2 treatment of the grain at acceptable cost/t and, depending on cost constraints, be suitable for handling other gases or gas mixtures such as CO_2 -air, CO_2 -air- methyl bromide, CO_2-air-phosphine, etc., which may possible by required in the future. Consultation between grain handling authorities, C.S.I.R.O., relevant engineering groups and industrial gas companies prior to the design and construction phases of new installations, or the modification phases of existing installations, should prove beneficial in this regard.

CARBON DIOXIDE PRODUCTION AND DISTRIBUTION

Most of the CO_2 production plants in Australia, with the exception of brewery CO_2 plants, which supply CO_2 to the various industry markets, are located in cities and towns along the Eastern, Southern and South-Western seaboard. Therefore there is good access by road and rail to the grain storage sites of the wheat growing areas of Australia. Production plants are located at Townsville and Brisbane, Queensland; Newcastle and Sydney, New South Wales; Melbourne, Victoria; Launcestion, Tasmania; Mt. Gambier and Adelaide, South Australia and Perth, Western Australia. The combined installed production capacity of these plants is c.a. 500-600 t/day.

Sources of raw CO_2 include flue gas from oil burning and from cement works, byproduct CO_2 from ethanol fermentation plants, synthetic ammonia plants and other chemical processes and CO_2 from a natural well at Mt. Gambier. Carbon dioxide is produced and marketed in three forms: bulk liquid, high pressure cylinder liquid and dry ice (solid CO_2). Because most of the CO_2 produced by these plants is used by the food and beverage industries it is manufactured to a very high degree of purity. Bulk liquid would generally contain about 99.9% CO_2, be odour free and have a moisture content on delivery of well below 50 ppm. Bulk liquid used for the purging of wheat storages is produced, stored and delivered at a pressure of 2067 kPa and a temperature of $-16.7^{o}C$. Factory storage facilities for bulk CO_2 vary from around 100 t to over 1000 t per site.

MULTI-BIN PURGING

The pressure of the CO_2 stream reaching the bin wall when purging a wheat storage facility consisting of, for example, fourteen 2000 t vertical steel bins may be chosen from near tanker pressure of 2067 kPa to near atmospheric pressure. The following describes a low pressure (50 kPa) multi-bin CO_2 circuit suitable for purging three bins simultaneously with an 80% CO_2-20% air mixture at purge rates of up to 1.25 t CO_2/h/bin. One advantage of this low pressure CO_2 circuit is that, when required, it allows the initial pressurised CO_2 stream to be used with a suitable injector to draw in and mix air with the CO^2 thus avoiding the need for a multi-stage blower or screw or piston compressor and the associated high power requirements. The purging circuit should be of simple design, leakproof, reliable, safe, require minimum on-site labour and have all valves, hoses and other equipment within easy access of the operator at ground level.

The individual bin modifications required to allow a purge rate of 1.25 t CO_2/h as an 80% CO_2-20% air mixture may be similar to those shown in Fig. 1. This shows a 75 mm dia. CO_2 injection tube covered by an internal 600 mm x 450 mm grain baffle which is used to ensure that the back-pressure at the grain face is less than 10 kPa under most operating conditions encountered. These baffles are essential to minimise back pressure at this point. During tests, pressures as high as 400 to 500 kPa were recorded with a number of bins not fitted with grain baffles. A 200 mm dia. vent gas tube is connected to the bin apex adjacent to the infeed chute and is carried down the outside of the bin to a 75 mm water seal located near ground level. The seal provides the bin with positive protection against over or under pressurisation. The maximum bin pessure during the purge phase is less than 50 mm water gauge. During the purge the injection tube is connected to the CO_2 distribution circuit (Figs. 2 and 3) with a 75 mm dia. flexible hose. The same hose is later used to connect the injection tube to a 3 m^3/min blower for recycling a stream of gas from the base of the bin to its apex during the subsequent treatment period.

Figs. 2 and 3 show a low pressure (50 kPa) CO_2 circuit suitable for purging fourteen 2000 t vertical steel bins at rates of up to 3.5 t CO_2/h, with three bins being purged simultaneously. A flow-restricting orifice in the line to each bin which provides a substantial part of the pressure drop in the CO_2 distribution circuit plus the very low (near atmospheric) back-pressures at the wheat face under each grain baffle ensure reasonably uniform purge rates for each set of three bins which are being purged. A sudden increase in line pressure and thus flow to one bin which may result if the CO_2 to the other two bins is shut off prematurely, before opening new bins, causes a rapid rise in the pressure drop across the orifice plate and in turn a rapid pressure rise at the vapouriser end. This opens a low pressure line dump (relief) valve to help protect the bin structure from over-pressurisation. The piping at each bin is arranged so that once purged the bin is isolated from the CO_2 distribution circuit as well as from all the other bins. During the purge phase the CO_2 content of the vent gas stream may be conveniently measured with a thermal conductivity type CO_2 meter (Gow-Mac Inc. Bound Brook, N.J., USA).

CARBON DIOXIDE VAPOURISER

It is desirable to vapourise the bulk liquid CO_2 at site and heat the resulting gas so that it enters the storage bin at near grain temperature to avoid any localised cooling of the grain. The CO_2 may be vapourised under pressure in a suitably designed receptacle using a heating medium such as electric power, steam, diesel fuel, propane, forced draught or natural draught. Bulk liquid CO_2 requires 350 kj/kg to convert it to gas at atmospheric pressure and at a temperature of 25°C.

The vapouriser unit should be robust, transportable, reliable, safe to operate, of relatively simple construction and of a type that can be easily maintained and readily repaired by local technicians in remote country towns. These requirements can be met by using a forced draught type vapouriser with electric superheating. A flow diagram of a unit with a nominal vapourising capacity of 3 t CO_2/h at an ambient temperature of 27°C is given in Fig. 4. This figure shows that at a rate of 3.5 t CO_2/h the forced draught vapourising element provides in excess of 90% of the total heat input using a fan power consumption of 15 kW compared to less than 10% of the heat input for a power consumption of 32 kW by the electric superheater elements. The air content of the exit CO_2 stream may be varied from zero to over 30% with an injector element. Both 100% CO_2 and 80% CO_2-air mixtures have been used successfully to purge wheat bins on a commerical basis in Australia. Fig. 5 shows the variation in the average vapouriser output for ambient temperatures varying from 0 to 40°C. Vapourising rates in the range of 2.5 to 3.5 t CO_2/h generally apply at the temperatures prevailing in the wheat areas of Australia during summer and early autumn. Optimum performance is obtained when the forced draught element is defrosted after each hour of operation for a period of 10 to 15 min by simply shutting off the CO_2 flow at the exit. Defrosting requires ambient temperatures in excess of $0^{o}C$. Figs. 10 to 13 show details of the vapouriser and its use in a number of purging operations including 16,400 t and 25,000 t horizontal shed-type bins.

The purging of very large storages of over 100,000 t capacity requires special consideration with respect to purging rate and CO_2 supplies. Unless the purge rate is sufficiently high, the CO_2 consumption can become excessive due to leakage of CO_2 from the bin to the atmosphere. A situation could occur where the CO_2 leakage rate just balances the CO_2 injection rate into the bin and a lethal concentration would be unobtainable.

SAFETY

Carbon dioxide gas is colourless, odourless and often difficult to detect by people particularly at low concentrations. The T.L.V., threshold limit value, for CO_2 in air is 5000 ppm which can be compared to the T.L.V. for methyl bromide of 5 ppm and for phosphine of 0.3 ppm. Whilst CO_2 is not necessarily dangerous at concentrations of a few per cent in air it will produce symptoms of deeper and faster breathing, nausea and dizziness when a person is exposed to concentrations of up to 9% for several minutes. Recovery from these symptoms is usually fairly rapid when the person is placed in a source of fresh air. Unconsciousness can occur in 5 to 10 min. when breathing air with a CO_2 content greater than 9%. With CO_2 concentration above 20% in air, death is likely in 20 to 30 min. unless the person is moved to fresh air sooner, artificial respiration is applied and medical attention is sought.

Since CO_2 gas is c.a. 50% heavier than air at ambient temperatures it will generally attain its highest concentration at the lowest parts of the workplace such as elevator pits, stairwells, drains, tunnels, etc. Adequate ventilation should be provided either by natural or mechanical means to ensure all work areas contain less CO_2 than the T.L.V. value before operators are allowed to enter. The CO_2 in many vertical bins may be exhausted to atmosphere with the recycle fan after opening the vent tube to allow air to enter at the bin apex. With some types of horizontal storages there will be a need to fit suitably sized exhaust fans to remove the CO_2 from the storage area prior to entry. Carbon dioxide concentrations in air may be conveniently measured with a Drager gas detection kit or other equipment (Dragerwerk A.G., Lubeck, Germany).

COSTS

The total cost for purging a grain bin with CO_2 excluding bin modification and sealing costs, may be broken up into three parts; CO_2 cost ex works, CO_2 delivery costs and the on-site purging costs. There can be differences in the CO_2 cost ex works from one centre to another due to various factors, one large one being the highly competitive nature of the gas industry. Delivery costs based on the use of 20 t capacity tankers can also vary between locations although they are usually very competitive. Both CO_2 ex works cost and delivery cost provide areas for reducing overall purging costs in a significant way but this depends on factors such as production and distribution costs, competition, marketing strategies, contractual arrangements and other factors applicable to a particular treatment.

The choice of equipment at site does not, apart from the on-site tanker costs, have a great bearing on the above costs. However, the on-site purging costs which are directly related to the purging time and which can amount to a fair proportion of the total cost can be minimised with the correct selection of equipment at the site. Particularly important is the CO_2 distribution, injection and vent gas piping necessary to allow bins to be purged at high CO_2 rates with maximum efficiency. On-site purging costs include charges for tanker waiting time, driver and operator expenses and wages, vapouriser hire and towing charges and power costs.

The following costs have been based on the premise that the bins at a terminal have been sealed and made suitably gastight by grain handling authority personnel and that the complete CO_2 purging operation is carried out by gas company operators. Some reduction in these costs could result if the purging operation was carried out by on-site grain handling people or by private contractors.

Fig. 6 shows the effect on the total CO_2 cost/t of wheat treated when the CO_2 purge rate is varied from 1 to 3 t/h for a terminal containing 14 x 2000 t capacity vertical steel bins filled to 95% volume when the terminal is located 100 km from the CO_2 plant. The comparison is also made for the terminal which is located 600 km from the CO_2 plant. The carbon dioxide cost ex works is taken at \$100; \$150 and \$200/t to allow for the variation in the ex works cost of CO_2 from one production plant to another. For example when the ex works cost of CO_2 is \$100/t and the wheat terminal is 100 km from the CO_2 plant the total CO_2 cost/t of wheat is 26.5, 20.0 and 18.1 cents for CO_2 purge rates of 1, 2 and 3 t/h, respectively. Similarly when the terminal is 600 km from the CO_2 plant these costs rise to 35.1, 28.4 and 26.7 cents, respectively.

Fig 7 shows a similar cost comparison for a 28,000 t horizontal bin filled to 60% volume. Here 56 t of CO_2 are necessary for an adequate purge of the bin compared to 28 t for the terminal described in Fig. 6. When the ex works cost of CO_2 is \$100/t and the wheat terminal is 100 km from the CO_2 plant the total CO_2 cost/t wheat treated is 48.6, 38.8 and 33.8 cents for CO_2 purge rates of 1, 2 and 3 t/h, respectively. If the terminal is 600 km from the CO_2 plant these costs rise to 61.5, 51.7 and 46.6 cents, respectively.

The effect on the total CO_2 cost/t of wheat treated due to varying the distance of the wheat terminal from the CO_2 plant when purging at a constant CO_2 rate of 3 t/h is shown in Figs. 8 and 9. Fig. 8 shows these costs for a terminal containing 14 x 2000 t capacity vertical steel bins filled to 95% volume for CO_2 ex works costs of \$100, \$125, \$150, \$175 and \$200/t. As an example when the CO_2 ex works cost is \$200/t the total CO_2 cost/t of wheat is 28.1, 31.6 and 36.7 cents for distances of 100, 300 and 600 km. respectively. Fig. 9 shows the same cost comparison for a 28,000 t horizontal bin filled to 60% volume. For a \$200/t ex works CO_2 cost the total CO_2 cost/t of wheat is 54.9, 60.1 and 67.8 cents for distances of 100, 300 and 600 km. respectively.

CONCLUSION

Carbon dioxide has been used successfully in Australia over a period of several years in trials and on a commercial basis to disinfest wheat which has been stored in bins that have been sealed to a suitable gastightness. It can be handled efficiently and economically by transporting it to site as a pressurised liquid in 20 t road tankers and vapourising it at low cost at rates in excess of 3 t/h with forced draught vapourisers. It is relatively safe to use and far less toxic to humans than phosphine and methyl bromide. The method does provide wheat which is free of insects and chemical residues at treatment costs which are very competitive with some currently used contact type insecticides. There is a strong and growing interest in the use of CO_2 for disinfesting stored grain by producers and grain handling and marketing authorities within Australia for the supply residue free grain to local and overseas markets as the demand for this type of grain increases.

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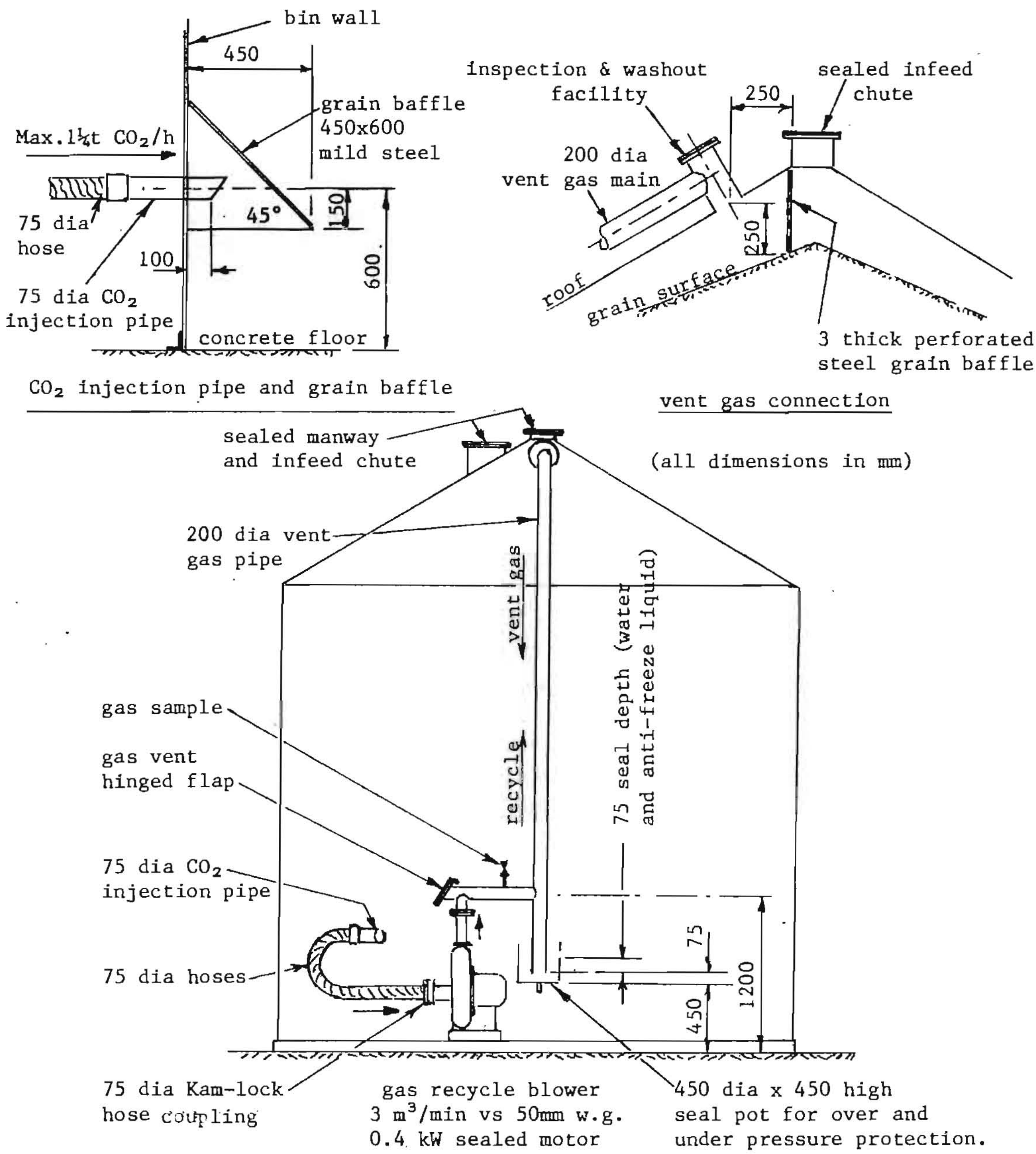

FIG. 1 Details of CO_2 piping and recycle gas fan for purging 2000 t capacity vertical steel wheat bin at rates of up to 1.25 t CO_2/h.

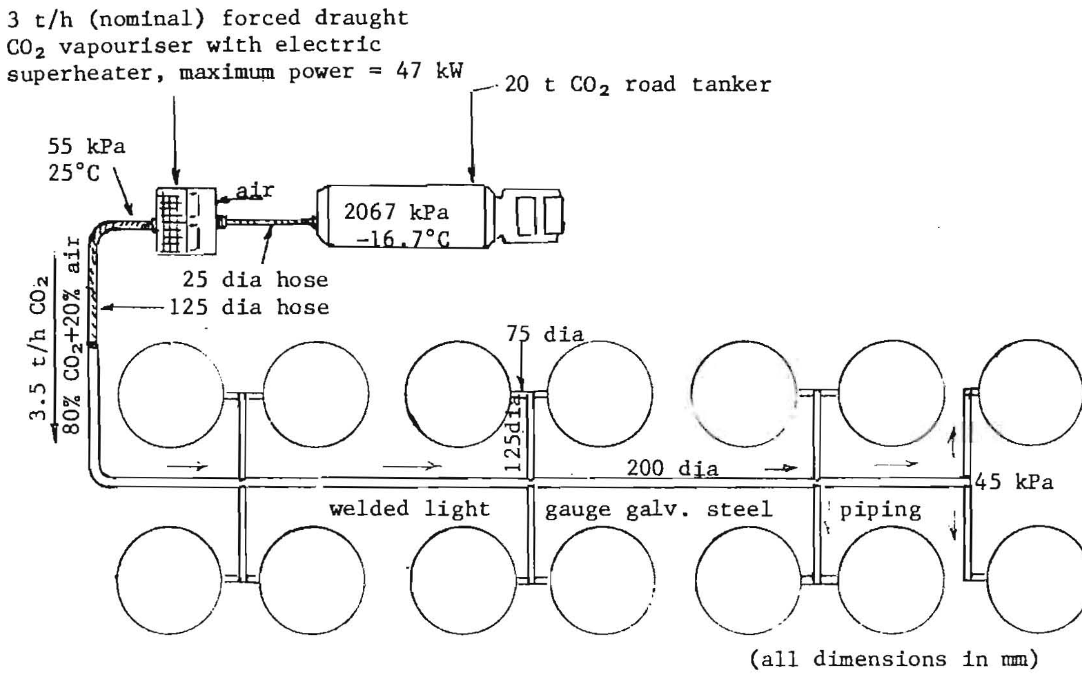

FIG. 2 Arrangement of low pressure gas circuit for purging fourteen 2000 t vertical steel wheat bins with an 80% CO_2-20% air mixture at a maximum rate of up to 3.5 t CO_2/h.

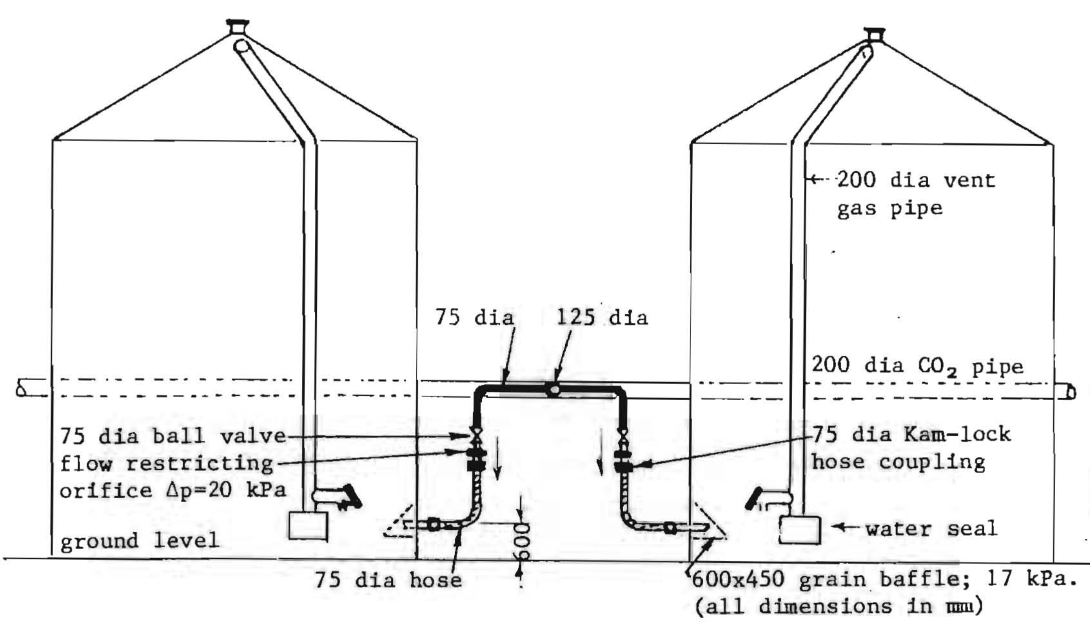

FIG. 3 Details of piping connections for purging 2000 t vertical steel wheat bins with an 80% CO_2 - 20% air mixture at up to 1.25 t CO_2/h each

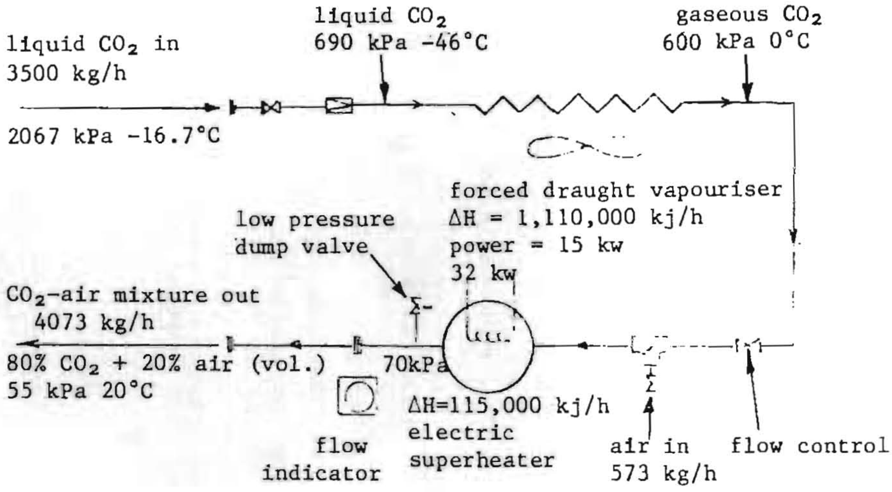

FIG. 4. Flow diagram of a nominal 3 t/h forced draught CO_2 vapouriser with electric superheater.

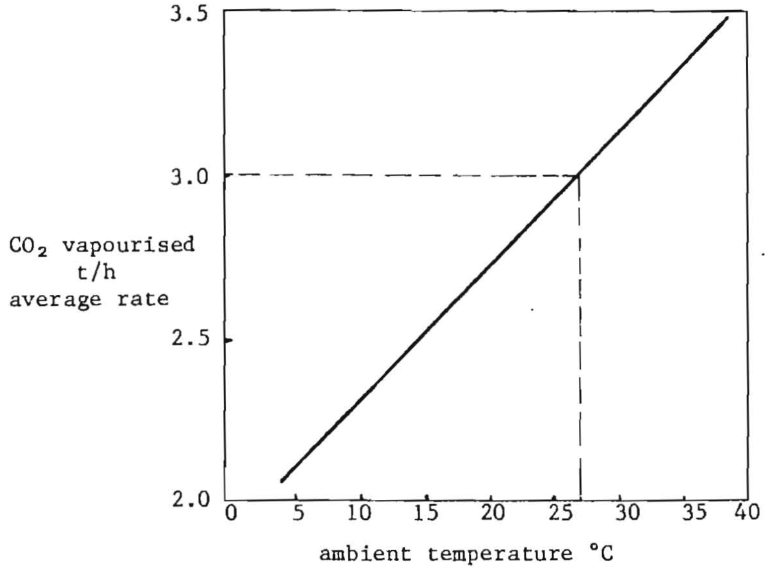

FIG. 5. CO_2 vapourising capacity of nominal 3 t/h vapouriser at various ambient temperatures. Total cycle = 75 min (60 min operating + 15 min defrost).

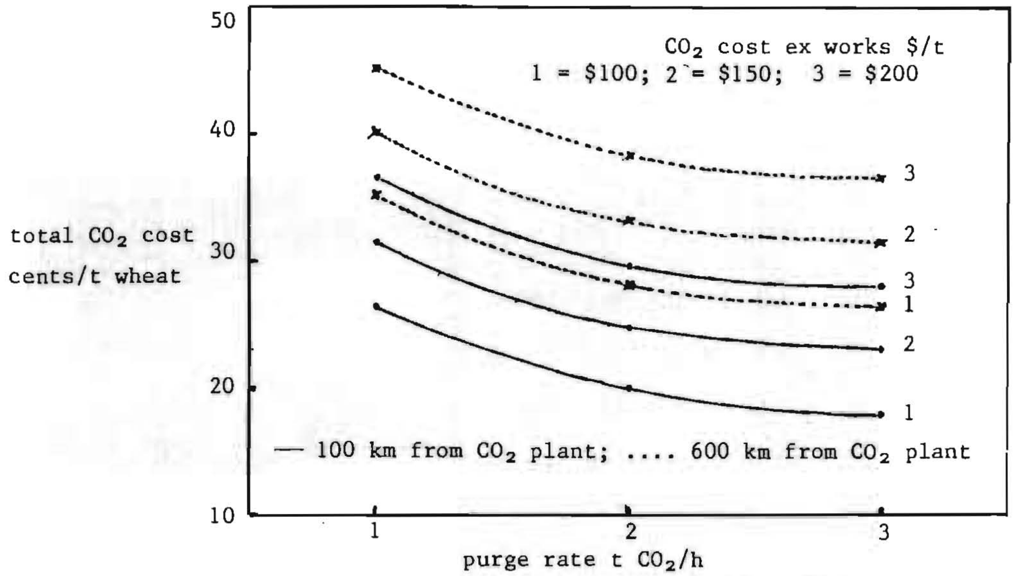

FIG. 6. Effect of purge rate on the total CO_2 cost when purging a 28000 tonne vertical, steel, multi-bin wheat terminal. Bins 95% full 5% headspace. CO_2 consumption 1 t/100 t wheat.

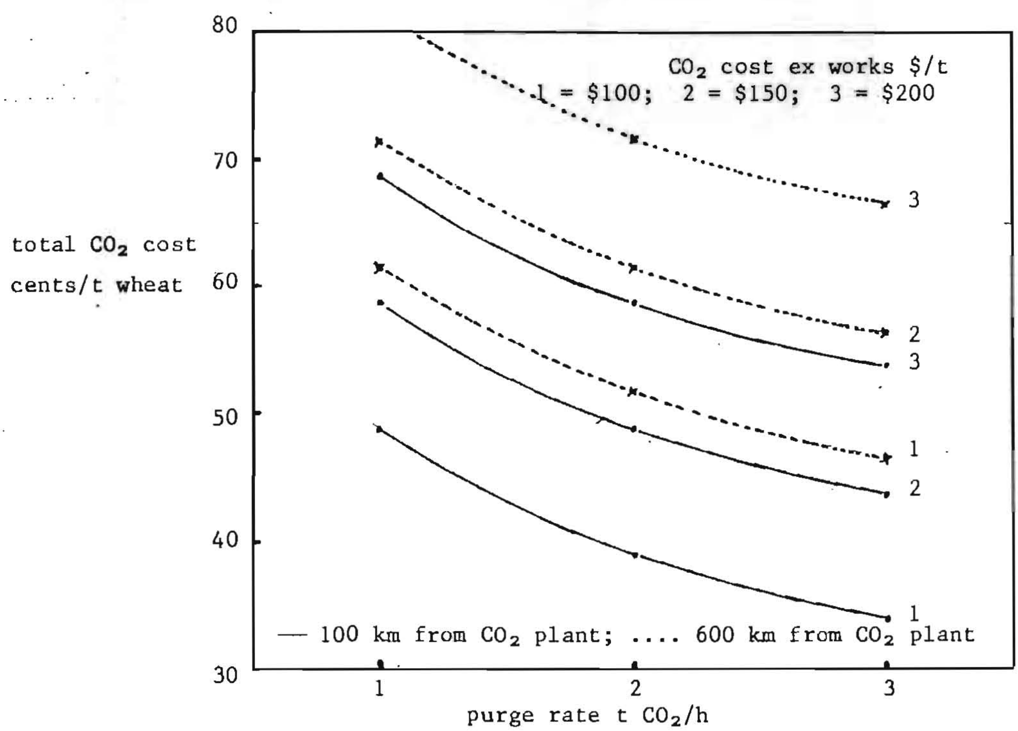

FIG. 7. Effect of purge rate on the total CO_2 cost when purging a 28000 tonne horizontal shed type wheat bin 60% full 40% headspace. CO_2 consumption 2 t/1000 t wheat

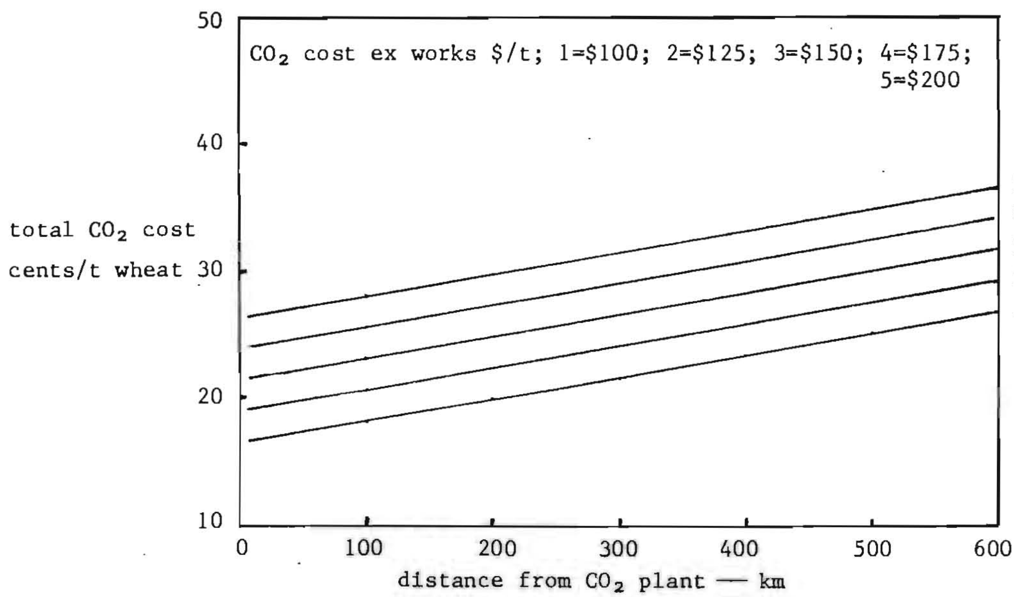

FIG. 8. Effect of distance from CO_2 plant on the total CO_2 cost when purging a 28,000 tonne vertical, steel, multi-bin wheat terminal at an average purge rate of 3 t CO_2/hr. Bins 95% full 5% headspace. CO_2 consumption 1 t/1000 t wheat.

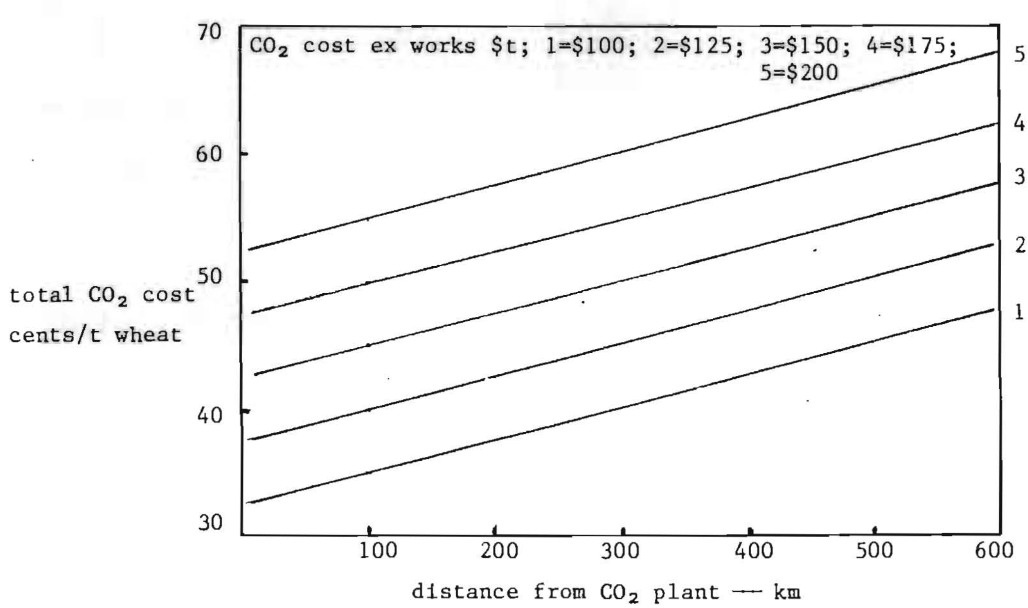

FIG. 9. Effect of distance from CO_2 plant on the total CO_2 cost when purging a 28,000 tonne horizontal shed type wheat bin at an average purge rate of 3 t CO_2/h. Bin 60% full 40% headspace. CO_2 consumption 2 t CO_2/1000 t wheat.

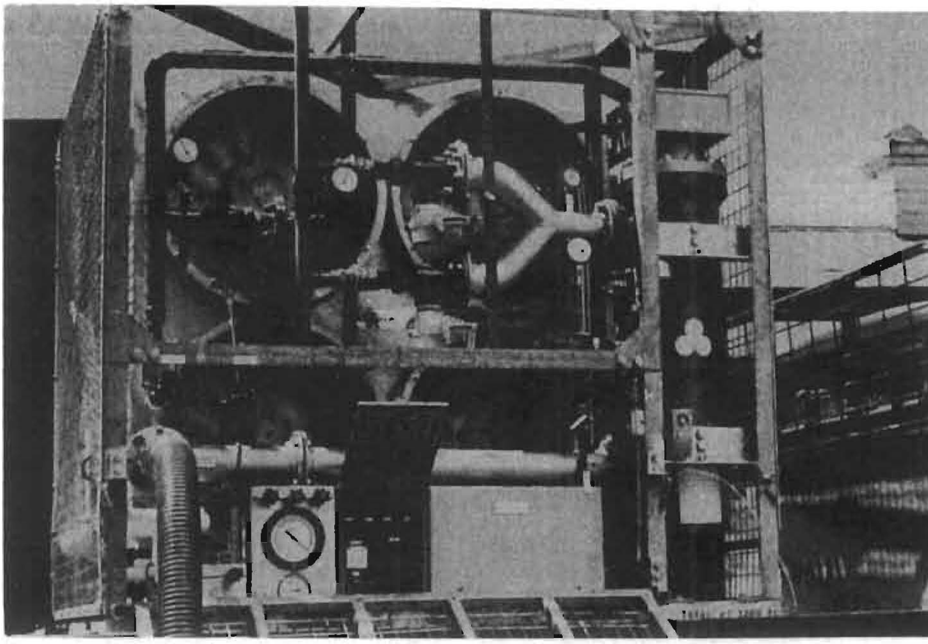

FIG. 10 View of nominal 3 t/h forced draught CO_2 vapouriser with electric superheater.

FIG. 11 Purging 2000 tonne capacity vertical steel bins with 3 t/h CO_2 vapouriser (Yarrawonga, Victoria, 1980)

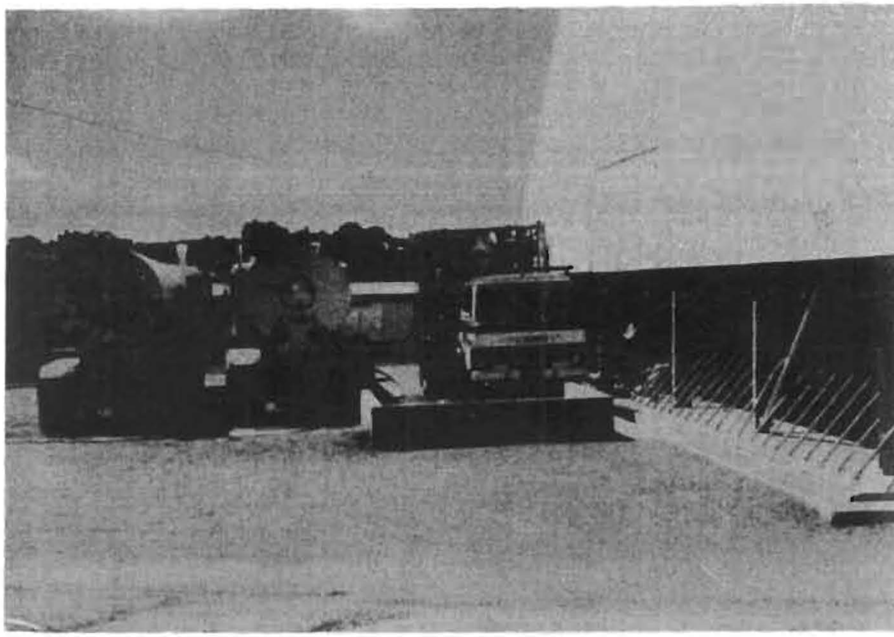

FIG. 12 Purging 16,400 tonne capacity horizontal shed-type galvanised iron bin with 3 t/h CO_2 vapouriser (Harden, N.S.W., 1979)

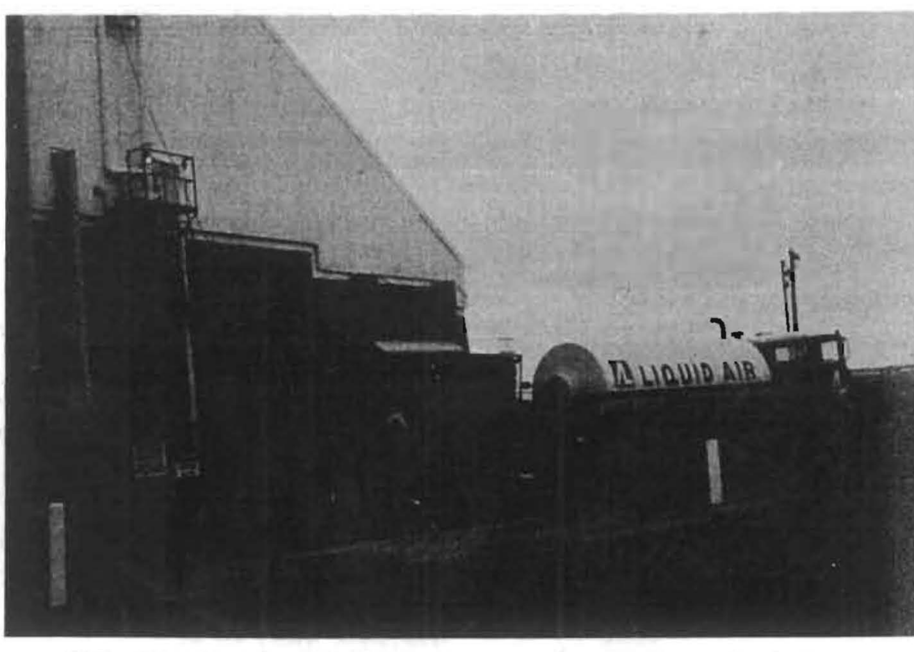

FIG. 13 Purging 25,000 tonne capacity horizontal shed-type concrete-galvanised iron bin with 3 t/h CO_2 vapouriser, (Cunderdin, W.A., 1981)