SYSTEMS OF SUPPLY OF NITROGEN FOR THE STORAGE OF GRAINS IN CONTROLLED ATMOSPHERE

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INTRODUCTION

In order to create and maintain a low-oxygen atmosphere in storage rooms for grains and other commodities a supply of nitrogen gas is needed to substitute the oxygen-enriched normal atmosphere. Nitrogen can be supplied in liquid state in pressure bottles or in case of big quantities -like normally needed for storage purposes- in tanks which are delivered by nitrogen producing factories through a distribution network more or less developped in the various countries. The cost of industrially produced nitrogen varies very much accordingly to the distances from the production factories or from main distribution-centers and depends upon the conditions of the road -or other communication-infrastructures. In Italy for instance selling price varies in a proportion of 1 : 4 and more from central distribution points like Rome, Milan etc. and distant periferic areas. In addition frequently there are difficulties in the supply, distribution and returning of the devices. Handling of the orders may create other kinds of organisatory troubles, especially in periods of strikes, emergencies in the transportation and other trying circumstances. Research of scientists and of the industry focused therefore increasingly on the development of relatively small equipments able to produce locally, directly on the storage premises, the required nitrogen avoiding the described inconveniences.

SYSTEMS OF LOCALLY PRODUCED NITROGEN

The first method of production of nitrogen was cryogenic separation of air. Incoming air is liquefied and its components are separated by distillation or rectification using their differing vapour pressure. It is a method which requires rather high electric supply (0.8 kWh/ Nm^3 N_2) and very high capital investment (see table 1). Operating cost is therefore rather high for small users and this kind of equipment is mainly recommended for large-scale facilities.

For purposes of creating approximately inert atmospheres the required nitrogen can be produced also by combustion of hydrocarbons, such as propane, butane, methane or similars. The obtained gas is relatively impure containing especially CO_2 and H_2O which must be removed by means of additional downstream molecular-sieve adsorbers, like zeolite molecular sieves, after passing a cooling system. The adsorption of the impurities takes place in an equipment consisting of two containers, one of which is alternatively operating in the adsorption phase at 3 + 7 bar of pressure and at room temperature. The second is working in the regeneration phase. Regeneration is obtained by creating with a vacuum-pump a depression of about 100 Torr contemporaneously flushing with the produced gas mixture. An example of combustion consuming oxygen and leaving the inert compounds like N_2 in the atmosphere is given by the following equations:

$$C_3H_8 + 5\ O_2 \qquad 3\ CO_2 + 4\ H_2O \quad (+\ N_2)$$
$$CH_4 + 2\ O_2 \qquad CO_2 + 2\ H_2O \quad (+\ N_2)$$

Even with the described complex procedure the total operation cost is nevertheless low and, considering the produced unit of gas nitrogen, more or less independent from the size of the equipment.

Servicing and maintenance with this kind of equipment is relatively complicated. The investment cost is also very reduced and only approximately one third or even less of the other described systems.

A recent interesting further development is the pressure-swing adsorption. It is based on multiple beds of molecular-sieve coke utilising the differing diffusion rates of oxygen and nitrogen molecules within the extremely small pores of the coke. Simultaneously with the oxygen are adsorbed also the water vapour and the carbon dioxide contained in the air, which simplifies the whole operation not requiring additional purification like the combustion system. For continuous operation a set of two adsorbers is provided, alternatively operating in adsorption and regeneration. In the adsorption (loading) phase oxygen is predominantely adsorbed while nitrogen passes through and leaves the unit. Optimal pressure in this phase is about 3 + 4 bar. After the loading phase the coke sieve is desorbed by depressurisation at 70 Torr. Loading and regeneration phases are relatively short in duration (about 60 s each). A big advantage of this system, is the simplicity of the operation and of the servicing. The degree of purity goes up to 99.9% by volume and can be regulated through regulation of the air-flow rate, of the pressure and of the periods for the loading and regeneration phases. The higher the purity, the lower the product-gas quantities. These can be increased, with the same other conditions, by increasing operating pressure. Energy consumption is proportional to purity, being e.g. 0.4 kWh / m^3 for 99% nitrogen and 0.6 kWh for 99.9% purity. Generally can be stated that the pressure-swing adsorber system (PSA-system) has low operational cost but on the other hand a rather high cost of investment, considerably higher than the equipments based on the combustion of hydrocarbon and subsequent purification.

All the three described systems are able to produce an atmosphere with a very high nitrogen content from 99 to 99.9%, keeping impurities (H_2O, CO_2, CO etc.) at extremely low levels. They are also adapted for usage in technologies where such requirements are demanded. Higher investment and operating cost have to be accepted in such cases.

It must be added that there are also quite a number of experiences (U.S.A., Australia, Israel) with less sophisticated applications for the treatment and preservation of grains, with acceptable results as regards disinfestation and quality. These technologies allow to make use of very simple equipments based also on the burning of hydrocarbons (natural gas, propane or similar) or other combustion materials, like ethanol or other alcohols. This signifies that in all localities there will be availibility of the required fuel. Likewise no particularly perfect gas-tightness is needed, cutting down investment- and maintenance-cost and increasing the feasibility of transforming existing conventional structures. There are types of simple burners which even don't require any electric energy and cooling water, with the effect of a remarkable reduction of the

Table 1 : Comparison of different systems of N_2 -production for small-volume consumption

System	Prod. Nm^3/h	Investment cost $Lit/Nm^3\ N_2/h$	Electric supply $kWh/Nm^3\ N_2$	Water $m^3/Nm^3\ N_2$	Fuel $kg/Nm^3\ N_2$	Operating cost Lit/Nm^3 (without assisting manpower)
Cryogenic separation	100	3.100.000	0.7 + 0.8	0.08	-	240
	50	4.500.000				
Hydrocarbon burner (with zeolite molecular sieve)	100	600.000	0.3 + 0.4	0.06	0.12	70
	50	880.000				
Simple burner	100	300.000	-	-	0.12	39
	50	500.000				
Pressure-swing adsorber	100	2.300.000	0.4 + 0.5	0.07	-	77
	50	3.400.000				

operating cost. Production capacity of the burners can reach 100-120 Nm^3 N_2 /h and even more.

ECONOMICS

At this point some economic figures might be useful in order to compare the competitiveness of the described systems. In table 1 (next page) a comparison of different systems of local nitrogen production is given, with indication of investment cost, operating cost and of the consumption of some utilities. Prices are based on the Italian market situation and given in Lire (e.g. electricity 85 Lit/kWh, water 50 Lit /m^3, propane-fuel 325 Lit/kg).

To calculate the cost of locally produced nitrogen some preliminary assumptions have to be made :

(1) Depreciation can be fixed from 15 to 19% of the initial cost, with an average of 18%.

(2) Maintenance is supposed to be from 4 to 6% of the initial cost varying accordingly to the requirements of the various types of machine.

(3) Sizing of the capacity of the equipment has to be calculated in order to cover the consumption in the purging- and in the maintenance- phase.

For purging a ratio of 1 + 1.5 m^3 of gas per m^3 of storage volume was found in most experiences in the field. Variation is determined also by the flow-rate of the gas, being inversely proportional to the velocity of flow. For the calculation of the maintenance gas the amount of the losses of the structure have to be known. These are extremely varying accordingly to the type of structure, accuracy of execution of the gas-seal, age of the silo or storage and various other factors. Average values found in field operations are ranging from 10 to 30 l per m^3 in 24 hours.

With such premisses we can calculate the nitrogen consumption for a full year operation in a fair gastight silo applying locally produced nitrogen as follows.

Table 2 : (see next page)

Table 2 : Nitrogen consumption in m^3 in the storage of grains

Storage capacity t	Purging phase (ratio 1 : 1.25)	Maintenance phase (average losses 20 l/m^3 /day) day	year
1.000	1.663	27	9.855
5.000	8.312	133	48.545
10.000	16.625	266	97.090
20.000	33.375	532	194.180
50.000	83.250	1.332	486.180

For the choice of the capacity of the nitrogen-producing equipment the following productions per day and per year of the most common types avaiable corresponding to the hourly production have to be considered.

Table 3 : Production capacity Nm^3 N_2

1 hour	24 hours (1 day)	8760 hours (1 year)
15	360	131.400
25	600	219.000
50	1.200	438.000
100	2.400	876.000

As a general rule capacity has to cover dayly requirements for maintenance and must give the possibility to do the purging in a reasonable time.

Examining the figures in table 2 and 3 we can ascertain:

- Even the equipments with the smallest nitrogen production are able to cover the requirements of maintenance up to 10.000 t of storage capacity. Middle size machines can cope with storage capacities up to 50.000 t. In good airtight conditions of the storage the

Table 4 : Cost of locally produced nitrogen

Storage capacity t	Total consumption N_2 / m^3	Cost Lit /m^3*			
		Cryogen.sep.	Simple burner	Hydroc.burner with purific.	Pressure-swing adsorber
1.000	11.518	4.729-6.491	559-664	938-1285	3.436-4.678
5.000	56.857	1.149-1.506	145-166	245-316	763-1.009
10.000	113.715	694-873	91-102	157-193	420-543
20.000	227.555	467-556	65-70	114-131	248-310
50.000	569.430	330-366	49-52	87-94	135-170

* The first number referres to a production of 50 m^3 / h, the second to a 100 m^3 / h production

smallest units are always sufficient.

- In order to accomplish the purging in an acceptable time it is advisable to choose machines with high nitrogen production (50, 100 or more m^3 per hour).

In table 4 we tried to calculate some production costs for the nitrogen, assuming different storage capacities and basing the calculation on the previously indicated premisses. Considering that the price of liquid nitrogen in Italy ranges in average from 200 to 400 Lire at a certain distance from the main distribution points and accordingly also to the delivered quantities it can be easily derived that even with an all the year around operation the use of nitrogen production equipments is not economical at very small storage capacities around 1000 + 2000 t. Comparing the various systems, cryogenic separation is scarcely competitive even in case of relatively large facilities. The pressure-swing adsorption in such cases begins to be economical with capacities of 20.000 t and up, whereas hydrocarbon burners, especially the simple types without purification are employable also at relatively low capacities (3000 + 5000 t). If a perfect gastightness enables to reduce the consumption of nitrogen and if the annual consumption is reduced on account of the shorter periods of storage (e.g. only short storage after disinfestation) only the simple burner system is left over. Some examples are given in table 5.

Table 5 : Cost of nitrogen in case of reduced storage time and losses (Lit / m^3)*

Time of operation	Losses/ day $1/m^3$	Total N_2 m^3	Hydrocarbon with purif.	Simple burner	PSA
1 month	10	2.06	312-555	184-330	1023-1970
	20	2.46	273-476	161-283	869-1662
3 months	10	2.85	245-420	144-249	761-1445
	20	4.05	193-317	113-187	558-1040
6 months	10	4.05	193-317	113-187	558-1040
	20	6.45	148-225	85-132	380-682

*Based on an equipment with a production capacity of 50 m^3 /h. The first number is referring to 10.000 t, the second to 20.000 t of storage capacity.

CONCLUSIONS

Supply of nitrogen for the disinfection and storage of grains is very often more practical and also economical if produced directly at the storage facilities with proper equipment instead of the delivery of commercial liquid nitrogen. This applies particularly to localities far-away from distribution centers, especially if difficulties in transportation, like insufficient roads, shortage in tanks, strikes, organizatory or other inconveniencies are given.

Among the various systems hydrocarbon burners are the most economical, whereas pressure-swing adsorbers, which are simplier in servicing and operating, fit in very well in large facilities, especially with long-term storage. One of the simpliest and doubtless the cheapest system is the use of simple burners without purification. Their field of application is limited to technologies where a certain level of O_2 (1-2%) and of CO_2 (up to 13-14%) is accepted. On the other hand such a technology simplifies also the construction of the storage structures or the transformation of existing facilities not requiring a very high airtightness. Maintenance of the structures is for the same reasons less demanding. This facilitates the application of the nitrogen method of disinfection and storage also in developping countries where most circumstances and conditions are favourable for its application.

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