THE FIRST ITALIAN LARGE SCALE FACILITIES FOR THE STORAGE OF CEREAL GRAINS IN NITROGEN.

TRANCHINO, L.[*], AGOSTINELLI, P.[**], COSTANTINI, A.[***] and SHEJBAL, J[****]

* ASSORENI, SVIL, San Donato Milanese, Milano, Italy.

** Società Romana di Macinazione, Roma, Italy.

*** ITALSILOS, Acquapendente, Italy

**** ASSORENI, Laboratori Ricerche di Base, Monterotondo (Roma), Italy

ABSTRACT

The main characteristics of the first industrial storage plants for cereal grains, operating according to the Snamprogetti preservation technology in nitrogen, are described. In particular the differences in technical solutions in function of the various preservation necessities are put into evidence.

The storage plants operate with excellent results since three years. The data accumulated during their operation permit to draw the following conclusions:

- the nitrogen preservation method can be applied also to industrial plants of large dimensions, obtaining in all parts of the bins conditions adequate for the satisfactory preservation of cereal grains;
- the investment costs for the instrumentation needed for the preservation in nitrogen do not cause significant variations in the overall investment costs of the storage plants;
- the nitrogen consumption during the preservation depends on the particular technical solutions adopted, yet they are in any case in the order of 2 - 5 SCM/ton.

INTRODUCTION

The first Italian large scale facilities for the storage of grains in nitrogen, operating since three years are:

(1) IVO, Tuscania: storage complex with 4 silos, 2,200 m^3 each.

The silos have a flat base and a conical roof; the construction material is folded galvanized steel for the cylinder and welded steel for the roof and the floor. The silo diameter is 13 m, the height of the cylinder is 15.3 m, the total height is 19 m.

(2) S.R.M., Roma: storage complex with silos of 600 m^3 each. The storage complex is composed of 26 fiber glass silos, 6 m in diameter and 20 m height. The silos are based on conical concrete bases coated with reinforced polyester painting connected to the cylinder.

These two complexes have very different characteristics either on the basis of preservation necessities (1 year preservation in the IVO plant, few months in the SRM plant) or on the basis of the product to be preserved (malting barley, and wheat for human consumption for the two plants respectively).

In order to build these two plants many technical and economic questions had to be solved, concerning:

1 - silo gasthightness

2 - nitrogen supply system

3 - plant safety

4 - interstitial atmosphere substitution

5 - maintaining of the controlled atmosphere.

These questions are briefly discussed in the following, and the experimental results obtained during the operation of the plants are reported.

SILO GASTIGHTNESS

To maintain the controlled atmosphere inside the silo, a good gastightness of the silo itself is necessary in order to avoid oxygen penetration from outside and/or large nitrogen consumption.

Many different industrial silos can satisfy this requirement: welded steel bins, folded galvanized steel bins, fiber glass bins, coated concrete silos.

The test for gastightness of the silo is normally performed before the loading, in order to seal the eventually discovered discontinuity in the structure. But the test is very difficult to be performed with an empty silo particularly for thin wall and/or metal silos, because the surrounding temperature changes produce substantially pressure variations in the silo and incoherent results of the test. Only a rough test may be performed with an empty silo.

More accurate results may be obtained performing the test after the grain loading because the gas temperature inside the silo changes much less, owing to the large heat capacity of the grain.

In any case some temperature variation in the head space occurs, so that for very gastight structures exact results may be obtained only with a 3 - 4 days pressostatic test.

The test is performed maintaining a slight positive pressure inside the silo for the whole test time with a pressostat which supplies measured quantities of gas when the pressure drops under set value P_s. With a filling ratio of 95%, the pressure variations related to the surrounding temperature variation (less than 30°C) are lower than 50 mm water column. So that the silo safety valve does not operate (the operating pressure of the valve is about 100 mm w.g.). The gas inside the silo in discharged only trough the discontinuities of the structure and the measured quantity Q of gas supplied to the silo to maintain the pressure over the P set is equal to gas loss from the silo at the medium pressure between P_{set} and P_{max}, attained during the test.

This quantity Q is a meaningful gastight parameter as it equals to the nitrogen consumption for the operation of the controlled atmosphere silo.

The measured values of Q for the two plants are reported in table 1. The values change from one silo to the others so that the minimum and the maximum of these values are reported.

To compare these values with published data of gastightness, we have calculated, from the measured values of Q, the usual gastight parameters:

- the constant flow rate F necessary to maintain the pressure inside the silo at a given constant value, in particular a 250 Pa. (about 25 mm w.g.), at constant internal temperature;
- the time T necessary for a pressure decay from 250 to 125 Pa. at constant internal temperature.

TABLE 1 SUMMARY OF GASTIGHTNESS TESTS:

Plant	Structure of the bin	Capacity of the bin (m^3)	Filling ratio	Measured gas consumption giving P medium = 45 mm w.g. (m^3/day)	Calculated time for a decay from 250 to 125 Pa. (h)	Calculated flow rate giving a constant pressure P = 250 Pa. (l/s)
IVO	folded steel, welded steel floor and roof	2260	0.95	4 - 6	5.8 - 8.6	0.03 - 0.05
SRM	fiber-glass painted concrete floor	600	0.92	4 - 8	1.1 - 2.2	0.03 - 0.06

Experimental values of these parameters are not presented because in these very gastight structures it was impossible to obtain reproduceable results owing to temperature variations.

NITROGEN SUPPLY SYSTEM

The nitrogen of the required purity for controlled atmosphere application may be supplied in different ways:

- liquid nitrogen supplied by a Commercial Company that also leases the storage and vaporization facilities;
- gaseous nitrogen production from an autonomous plant joined to the grain storage complex. Different kinds of nitrogen production plants may be utilized: combustion, molecular sieve, air liquefaction plants.

Yet the relatively low cost of the liquid nitrogen supplied by commercial companies in Italy (about 15 ¢/m^3 for large nitrogen consumption in 1978) makes the utilization of autonomous nitrogen production plants economic only for large complexes of not less than 50,000 ton capacity. Therefore the nitrogen necessary for the operation of the two plants has been supplied by commercial Italian companies.

The difference in the nitrogen flow rate and consumption during the purge and maintenance operations suggests the utilization of different facilities for the two operations:

- a mobile large liquid nitrogen storage tank, having a very efficient vaporization facility, is used for purging the air in the silo;
- a static small liquid nitrogen storage tank is using for maintaining the controlled atmosphere inside the silo.

PLANT SAFETY

A pressure relief valve must be fitted to the roof of the silo in order to prevent excessive pressure build up or reduction, which may cause structural damage to the silo.

The two plants utilize a two plate valve operating at 100 mm w.g. A hydraulic seal on the nitrogen supply line prevents any excessive pressure build up during the purge of the air in the silo.

The hazard due to the lack of oxygen inside the silo is prevented excluding the possibility for men to get into the structures during the controlled atmosphere operation.

At unloading of the silos the oxygen content in the internal atmosphere must be tested and ventilated if necessary before the personal entry of a person is allowed.

SUBSTITUTION OF THE INTERSTITIAL ATMOSPHERE

The substitution of the interstitial atmosphere for a grain bulk stored in a large silo and/or with a low hight/diameter ratio presents some difficulties from the efficiency and nitrogen consumption points of view.

Better conditions should be attained by a plug flow of the supplied nitrogen. Actually strong diffucion phenomena occur between the nitrogen front and the air inside the bulk of the grains and still more in the headspace.

Moreover the convective currents, caused by the temperature gradients inside the bulk of the grains and by the temperature differences at the walls, carry the nitrogen along preferential directions enhancing the diffusion phenomena.

For the two plants the purge was performed supplying gaseous nitrogen to the bottom of the silo at a constant flow rate. We measured the oxygen content in the atmosphere different points in the silo and at different times during the purging operation.

These results have been utilized to test the purging model that assumes complete displacement of the gas in the load space and perfect mixing in the headspace of the storage bin (Banks, 1979).

According to this model to oxygen concentration $(C)_x$ in the load space at a distance x from the nitrogen inlet must present a discontinuous reduction from 21% to 0% at nitrogen front arrival time

$$(t_a)_x = \frac{n(V_B)_x}{W}$$

that is:

$(C)_x = 21\%$ when $t < (t_a)_x$

$(C)_x = 0\%$ when $t > (t_a)_x$

where $(V_B)_x$ is the volume of the stored product, from the nitrogen inlet to the section x of the silo, n is the product porosity, W is the nitrogen flow rate.

At the outlet of the silo the oxygen concentration C predicted by the model is an exponential function of time beginning from the nitrogen front arrival time to the border of the load space:

$$t_a = \frac{n\, V_B}{W}$$

that is:

$$C = 21\% \qquad \text{when } t < t_a$$

$$C = 21 \exp\left[-\frac{t - t_a}{\tau}\right] \qquad \text{when } t > t_a$$

where $\tau = \frac{V_{HS}}{W}$

and where V_B is the total volume of the load space and V_{HS} is the volume of headspace.

The comparison between theoretical and experimental results is shown in figures 1 and 2 for two tests performed at the SRM plant at different purging flow rates. The indicated values of the velocity refer to the cross section of the bin.

A shift of the experimental results from the theoretical values in the load space appears: large axial and radial diffusion phenomena appear in the middle section of the silo. The nitrogen rises quicker along the axis of the silo and along the wall facing the sun than along the other wall.

Convective fluxes may be responsible for this behaviour since the temperature of the wheat was greater than the ambient temperature.

On the contrary at the outlet section of the silo a quite good fitting of the experimental results was obtained. The fitting is in any case better at the higher purging velocity.

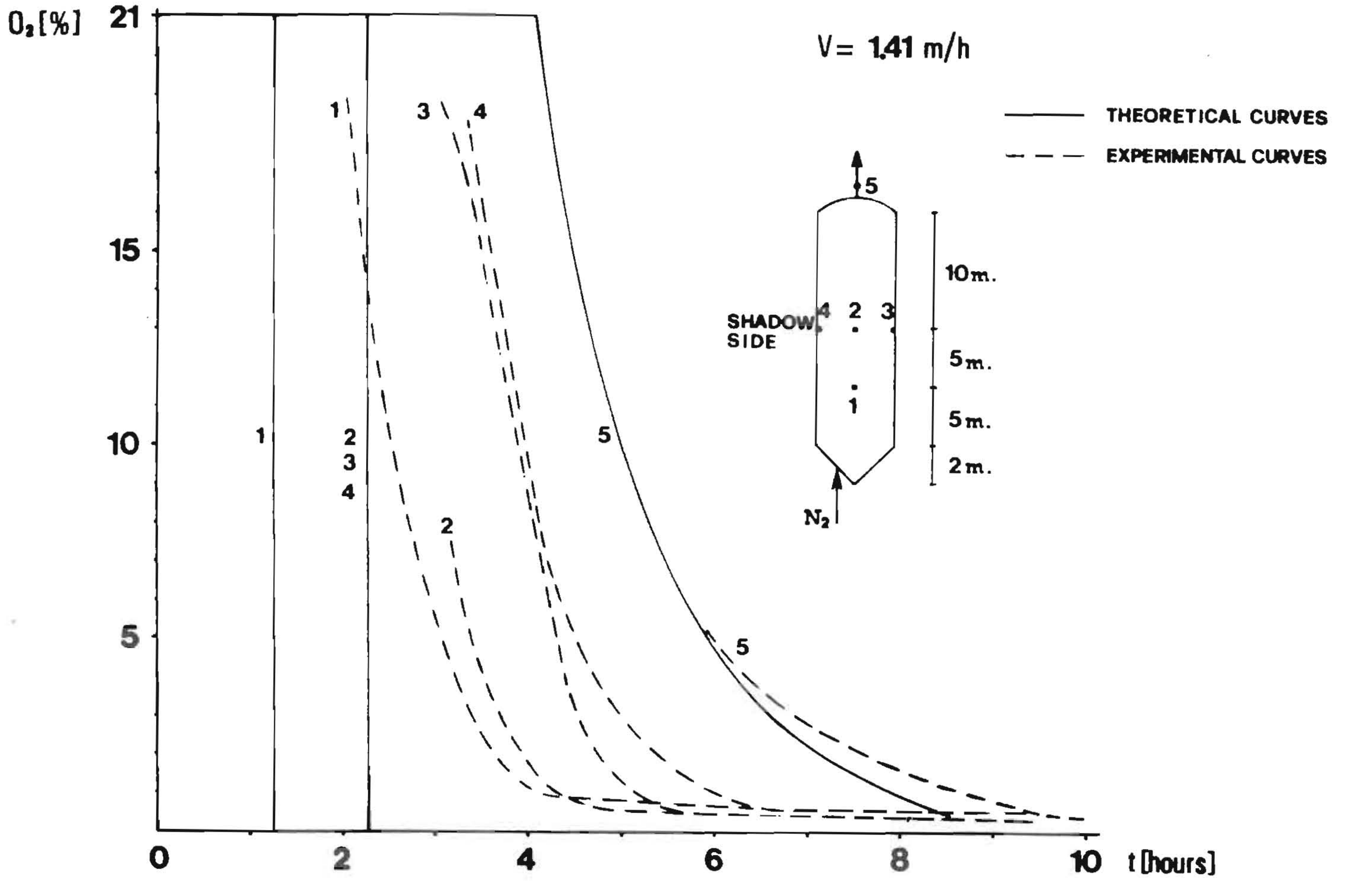

Fig.1. Comparison between theoretical and experimental results of a purging test in a SRM plant fiberglass bin at gas velocity of 1.41 m/h.

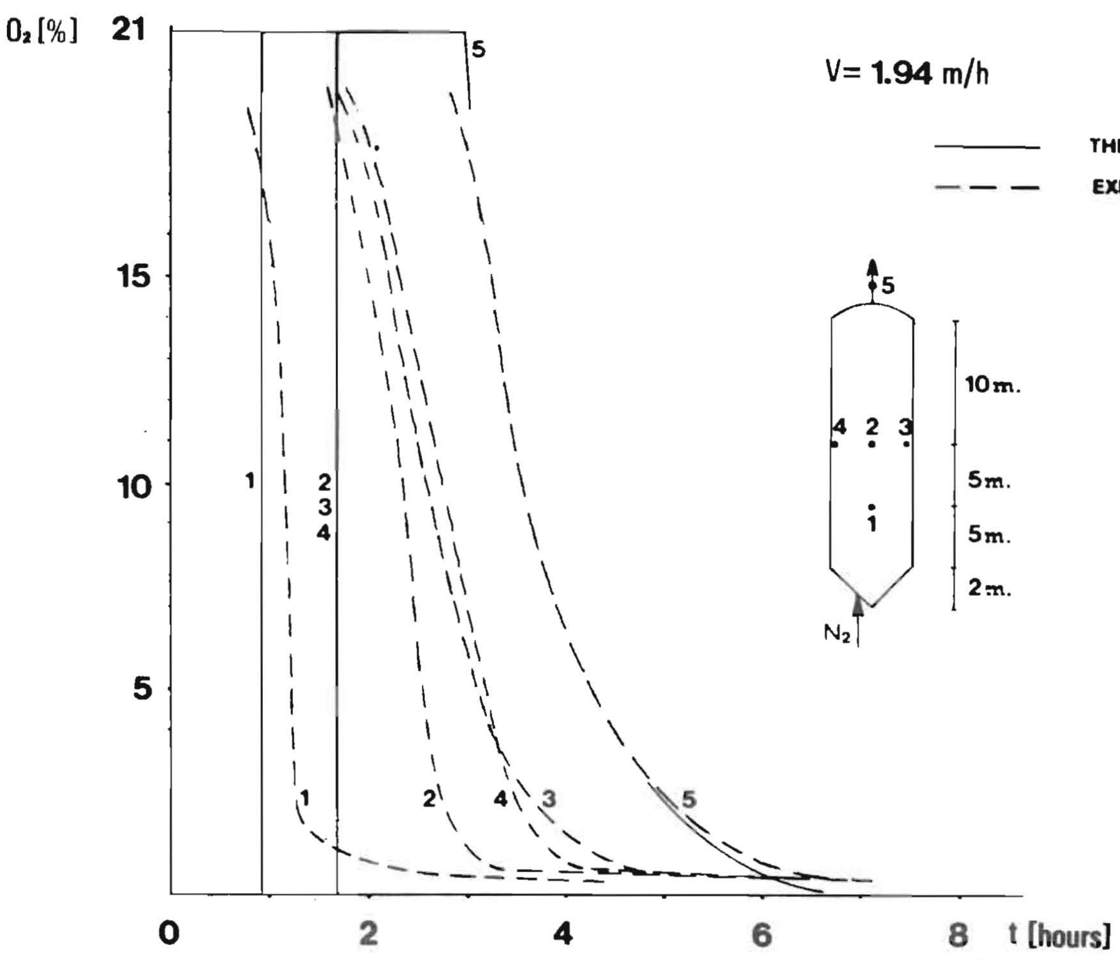

Fig.2. Comparison between theoretical and experimental results of a purging test in a SRM plant fiberglass bin at gas velocity of 1.94 m/h.

To summarize the results obtained during the purge operation in the two plants, we can consider the efficiency of purging E defined as the ratio of the nitrogen consumption predicted by the model and the experimental one V_G:

$$E = 100 \frac{n V_B + V_{HS} \ln \frac{21}{C}}{V_G}$$

In table 2 the E values obtained during the tests performed at the two plants, to a residual oxygen concentration of 0.5% vol. at the end of purging, are reported.

A clear increase in the efficiency with an increasing purge flow rate appears. Moreover, at the same flow rate, a greater efficiency occurs in the test performed at the SRM plant in comparison to the IVO plant. The greater ration of the height to the diameter of the silos (3.3 versus 1.3) may be responsible for the greater efficiency in the SRM test.

CONTROLLED ATMOSPHERE MAINTENANCE

After purging the silo it is necessary to maintain a constant value of the controlled atmosphere composition. Oxygen may penetrate inside the silo owing to convection and/or molecular diffusion.

In order to prevent this phenomenon in the two plants, a slight positive pressure was maintained in the silo. In this way convective fluxes from outside are present and diffusion is hindered by the overall flow rate from inside to outside. To reduce nitrogen consumption, the pressure of the pressostat was set at the lowest value capable to avoid any increase in the oxygen content: about 20 mm w.g.

The pressure variation inside a silo of the IVO plant is reported in fig. 3. The pressure increases during the morning from the set value, P = 20 mm w.g., attaining a maximum value of about 70 mm w.g., which is less than the operating pressure of the safety valve.

TABLE 2 SUMMARY OF PURGING TESTS:

Plant	Filling ratio	Average purge flow rate (m^3/h)	Equivalent Velocity in empty silo (m/h)	Final head space oxygen content (% vol)	Efficiency (%)
IVO	0.95	22	0.17	0.5	33
IVO	0.95	66	0.50	0.5	50
IVO	0.95	133	1.00	0.5	67
IVO	0.95	200	1.50	0.5	83
SRM	0.92	40	1.41	0.5	91
SRM	0.92	55	1.94	0.5	94

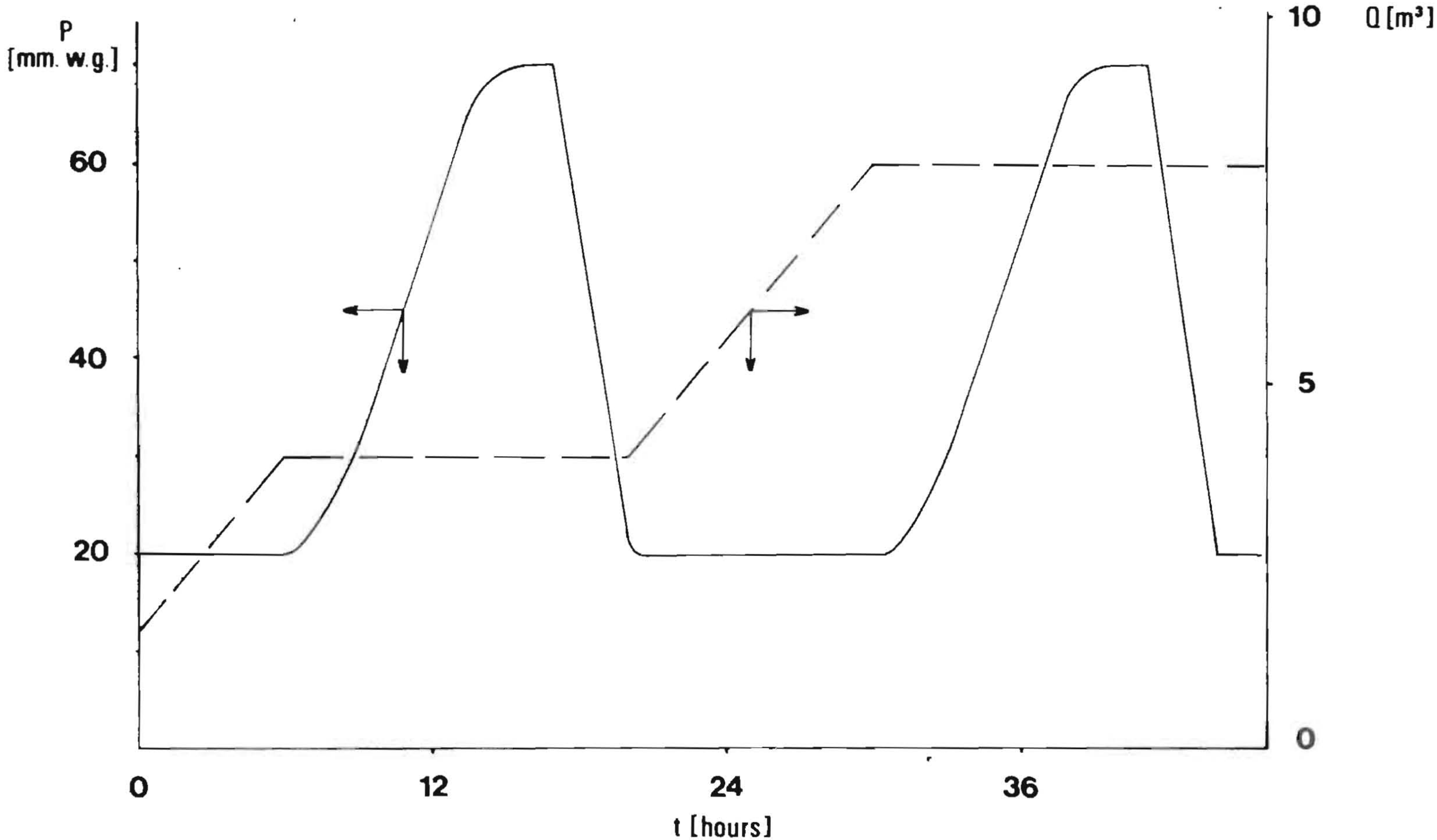

Fig.3. Diurnal changes in pressure in an IVO plant metal bin and nitrogen consumption for the maintenance of P_{min} = 20 mm w.g.

This maximum value is in agreement with the prediction that may be done knowing the filling ratio and the headspace temperature variation:

$$P_{max} = P_{set} \left[1 + \frac{V_{HS}}{V_{HS} + V_B} \frac{\Delta T}{T} \right]$$

where T is the initial headspace temperature (°K).

It appears that for a given headspace temperature variation, such a limit value of the filling ratio exists that below it P_{max} becomes greater than the operation pressure of the safety valve and very large nitrogen consumption for the maintenance builds up.

In fig. 3 the maintenance nitrogen consumption is also reported: during the morning the pressure is greater than P_{set} and the nitrogen consumption is zero;
in the night a nitrogen consumption equal to the gas loss during the whole day occurs. This consumption was 4 m^3/day for the tested silo.

CONCLUSIONS

The data accumulated during the operation of the first industrial plants for the storage of cereal grains in nitrogen, allow to draw the following conclusion:

- the nitrogen preservation method can be applied also to industrial plants of large dimensions, obtaining in all parts of the bin condition adequate for the satisfactory preservation of the cereal grains;
- the total nitrogen consumptions measured during the operation of the IVO plant, at near to optimum purge velocity, are about 0.9 and 2 m^3/ton for 1 month and 1 year preservation time respectively (table 3);

TABLE 3: SUMMARY OF NITROGEN CONSUMPTIONS

Plant	Load (ton)	Purge		Maintenance		Total consumptions	
		Flow rate (m^3/h)	Nitrogen consumptions (m^3)	Consumptions for 1 month (m^3)	Consumptions for 1 year (m^3)	for 1 month m^3/ton	for 1 year m^3/ton
IVO	1600	200	1356	120 ÷ 180	1460 ÷ 2190	0.92 ÷ 0.96	1.76 ÷ 2.22
SRM	440	55	366	120 ÷ 240	1460 ÷ 2920	1.10 ÷ 1.38	4.15 ÷ 7.47

- the total nitrogen consumptions measured at the SRM plant are 1.2 and 5.8 m^3/ton for 1 month and 1 year preservation time respectively (table 3).

The high value of the surface to volume ratio for the SRM silos is responsible for higher nitrogen consumption.

ACKNOWLEDGEMENTS

The authors wish to thank the ASSORENI staff: Messrs.P. Catani, R. Cavaioli and M. Marini for their invaluable contribution to the success of this work.

REFERENCES

Banks, H.J., 1979. Recent advances in the use of modified atmospheres for stored product pest control. Proceedings of the Second Intern. Working Conf. on Stored-Product Entomology, Ibadan, Nigeria, pp. 198-217.