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Systems for Producing Radon-free Compressed Air: Compressed Air - Report IV

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Introduction

For the purposes of building a full-scale system for producing radon-free compressed air to operate the diaphragm pumps[1] (see Appendix 1) in the water systems, and for other applications as well, the specifications given in table 1 have to be taken into account.

Table 1. Specifications for compressed air requirements to operate diaphragm pumps in the water systems

Compressed air supply pressure	100 psi
Compressed air flow rate	100 scfm
Dew point of compressed air	-40 ^{o}C
Concentration of radon in supply air	3 pCi/l
Minimum reduction factor for radon	100
Time for which reduction must be maintained	10 days ← 7

From the tests completed recently[2] at the SNO underground laboratory at the INCO Creighton mine it was found that activated charcoal has considerable adsorption capacity even at room temperature for the removal of radon from compressed air. It was also found that the capacity increases by about a factor of 2 for a 30 ^{o}C lower temperature of the column from room temperature. In addition, all other parameters being the same the holding capacity of the charcoal before radon breaks through the column is found to be a function of the amount of charcoal. It was also found that the column may be regenerated by purging with CO_2. These characteristics may be successfully utilized in the designing of alternative systems for radon removal from the compressed air.

This report deals with sizing typical systems at the conceptual level, arriving at some cost estimates for such systems, and identifying further actions necessary before full-scale systems may be designed.

Alternative systems with activated charcoal

The alternative approaches in designing a full-scale system consist of : 1. Passive systems at room temperature, 2. Passive systems at lower than room temperature, 3. Active systems at room temperature, and 4. Active systems at lower than room temperature. The difference between passive and active systems is in the method of dealing with the radon after it is removed from the compressed air stream.

While the passive systems try to hold the radon (^{222}Rn) on the activated charcoal and allow it to decay with the characteristic half-life (3.83 d) until the desired reduction in radon level is achieved, active systems try to achieve the same goal by purging periodically the captured radon from the charcoal. Therefore, passive systems tend to be much larger than active systems as are room temperature systems compared with low temperature systems of comparable radon reduction capacities. Therefore, it can be seen that while the capital costs are much higher for room temperature passive systems than active systems, operating expenses may be a significant cost in the long run for active systems as well as systems operating at less than room temperature.

The design parameters and DAC

The design parameters are the flow rate of air (f lpm), the retention time (t min) required at the radon reduction factor (R), and the amount of activated charcoal used (w g) to get the holding time at that level. In the context of adsorption from flowing streams of gases the dynamic adsorption coefficient[3] was defined as

$$DAC = f * t / w \qquad \ldots 1$$

which may be used to scale up measured values of the parameters to arrive at various designs of active and passive systems.

The measured values of the parameters for the activated charcoal used in the preliminary study[2] with a 3/4" dia x 12 " long column are given in table 2.

Table 2. Summary of measured values of design parameters for the activated charcoal used in the preliminary study

Dew point of compressed air		-40^oC
Flow rate of air through column		10 lpm
Retention time at less than 100th ambient level of radon at inlet		30 min
Weight of activated charcoal in column		45 g
Gain in retention time by cooling to -10^oC		x 2 (60 min instead of 30 min)
Purge gas CO_2	flow rate	10 lpm
Purge gas CO_2	flow time	10 min
Rinse gas N_2	flow rate	10 lpm
Rinse gas N_2	flow time	5 min

The charcoal column was on the low pressure side of the pressure regulator on the compressed air line.

The break-through time for radon is defined as the time at which the radon level in the air at the outlet of the column reaches the ambient level of radon at the inlet of the column. This was found to be 90 min with a 10 to 90% time of about 35 min. The value of DAC calculated from equation 1 for the activated charcoal used in the test column was found to be 20 l / g at room temperature (22°C). This value is about five times larger than the best value reported by Nakayama[4] et al and may be related to the finer mesh size of the charcoal used.

Using the specifications from table 1 and the measured values from table 2 in equation 1 the following systems may be visualized for producing radon-free compressed air.

Totally passive room temperature system with a 40 d holding time

With a flow rate of 100 SCFM and a breakthrough time of 40 d (10 half-lives of ^{222}Rn) the amount of activated charcoal may be calculated to be 26,000 kg (57,000 lbs). At a retail cost of $3/lb the cost of charcoal alone is about $170K. This may be an over estimate of the cost of charcoal unless a significantly lower cost can be obtained for bulk supply of such a large quantity of activated charcoal.

Even if the supply air comes from INCO, thereby avoiding the cost of the air compressor, the cost of a pressure vessel holding the amount of charcoal must be taken into account in capital costs in addition to the cost of operating the air drier.

The cost of the charcoal may be reduced by a factor of two by accepting a radon level of a tenth of the ambient level. A further reduction in cost by a factor of four may be achieved if the holding time is reduced to ten days thereby reducing the cost of charcoal to about $20K.

Alternately, the same system may be visualized with the charcoal at the inlet of the compressor rather than putting compressed air through the charcoal. In this case, the cost of the compressor, a buffer tank, and air filters need to be taken into account.

In this context, the performance characteristics of the radon-free compressed air system operated by Kamiokande group[5] may be of particular interest (see Appendix 2). After compressing the air to 7.5 kg/cm^2 (107 psi) it was dried to a dew point of -24°C before putting through the charcoal columns. There were four charcoal columns in series (0.8 m dia x 4 m high each) containing a total of 4000 kg of charcoal. The first two columns were at room temperature separated by a cooler from the second two columns. The pressure after the second two columns dropped to 0.95 kg/cm^2 (14 psi) at an air flow of 10-15 m^3/h (about 5-8 cfm). Radon reduction factors of 1400 and 30 were reported between the inlet and outlet of the first two columns, and the inlet and outlet of the second two columns respectively during continuous operation for one month from an ambient input level of about 38 pCi/l (1400 Bq/m^3).

Cooled passive systems

The amount of charcoal used in the system proposed above may be reduced by an order of magnitude by cooling the compressed air to -80°C. The cost of a cooler to cool air at room temperature (20°C) to -80°C at a flow of 100 SCFM is estimated[6] at $60K While gaining size reductions, because space is at a premium at the underground site, not much seems to be gained in over all cost of the radon-free system. In addition, the operating cost goes up because of usage of electricity and the added cost of maintenance of the cooler.

Scaled up versions of the systems built at Argonne National Laboratory[7] and NASA[8] may be copied and built to our specifications. The system at ANL used 150 lbs of activated charcoal (6-8 mesh) and an air chiller capable of cooling 30 scfm air to -70°C using an air-air heat exchanger. Continuous operation at radon levels below sub-pCi/l were reported.

The system at NASA used LN_2 cooled heat exchangers and about 150 lbs of activated charcoal to produce radon-free air at 10-60 SCFM, and was shut down[9] after about five years of operation due to the very high operating costs for LN_2. This option seems to be out of question for SNO purposes because of exorbitant capital and operating costs estimated in millions of dollars.

Active systems

There are no known designs at the moment neither available commercially nor operated in research laboratories. If designed and built by SNO this concept seems to have the potential for a patentable technology to produce radon-free air in large volumes at low cost.

The concept utilizes radon adsorption characteristics of activated charcoal coupled with radon desorption characteristics reported by Nakayama[4] et al using CO_2 as a purge gas. The characteristics of a small prototype column[2] are summarized in table 2 given above. This column produces air at radon levels a hundred times below the ambient level of 3 pCi/l for a minimum of 30 min at flow rates of 10 lpm. In combination with a second column while the first one is regenerated with the purge gas, a continuous stream of compressed air may be produced with radon levels lower than one hundred times the ambient inlet level.

The specifications for the scaled-up version of the system are given in table 3. They seem to be encouraging from a capital cost point of view because of smaller requirements of materials compared to completely passive systems.

Discussion of the full-scale designs

The purge gas requirements reported in table 3 for the full-scale active system may not make the active system a viable alternative to the passive systems without recovery of the purge gas. At $45 per cylinder of about 11K litres of CO_2 the cost of operating the system without purge gas recovery will be prohibitively expensive and environmentally unacceptable.

Table 3. Specifications for a full-scale active system using activated charcoal and CO_2 as a purge gas.

Dew point of compressed air		-40°C
Flow rate of air through column		100 SCFM (3000 lpm)
Retention time at less than 100th ambient level of radon at inlet		30 min
Weight of activated charcoal in column		13.5 kg
Number of columns required		2
Purge gas CO_2	flow rate	3000 lpm
Purge gas CO_2	flow time	10 min
Rinse gas N_2	flow rate	3000 lpm
Rinse gas N_2	flow time	5 min

In the scaling-up of the test column to a full-scale system the test column design is duplicated to accommodate the full-scale flow rate by placing the required number of columns in parallel. Therefore, the purge gas requirement is scaled-up accordingly. However, this procedure does not take into account what will happen if the purge gas is recirculated to regenerate the column or if a given flow rate will purge several columns in series.

Also, the recovery of the purge gas is contingent upon the fact that it can be separated from radon which is eluted from the column when the column is purged.

In addition, the adsorption and desorption mechanisms are not fully understood from the tests completed with the single column and with two columns in parallel. It is not readily clear how to interpret the observations that the flow capacity doubled with two columns in parallel for the same breakthrough time or alternately, the breakthrough time doubled with two columns in parallel when the flow is the same. ?

The reduction of radon by the column may be due to size exclusion and not due to physisorption on activated charcoal. The larger radon atoms may be taking longer time to break through the activated charcoal column because they are slowed down in the microchannels created by the activation process in the charcoal. If this is the dominant mechanism then keeping the flow rate the same, changing the radon activity level of the incoming air with the same column should only change the activity level at breakthrough and not the breakthrough-time itself. Therefore, further investigations are needed before full-scale systems may be designed. 1

Similarly, the passive systems may not be as expensive as they appear to be in the above designs if the holding times and the radon reduction factors are optimized to meet the actual requirements. The holding times are related to total usage of compressed air at full flow rates. Therefore, the compressed air actual usage requirements must be fully assessed and matched to actual experiments planned in the future in water systems rather than arbitrarily chose the holding times and reduction factors.

Conclusions

Therefore, further assessment is needed to get information on usage requirements of compressed air in future experiments and operations in water systems. In particular, not only should the flow requirement be confirmed but also the radon reduction factors and holding time must be confirmed as all the three parameters are crucial to the sizing of both active and passive systems. (2)

The characteristics of the active column may be investigated further by varying only the radon concentration level while keeping all other parameters like the flow rate, mass of charcoal and the temperature of the column the same. Since diffusion constants are inversely proportional to pressure the adsorption characteristic of the column must also be determined with the column on the high pressure side of the pressure regulator on the compressed air line. (1) (3)

The desorption characteristics of the column must be investigated further to determine the effectiveness of recycling the purge gas without radon separation The purge gas separation and recovery methods should be investigated contingent upon the results of recycling the purge gas. (4)

In addition, regeneration of the charcoal column with high temperature radon free air or steam may also be investigated as an alternative to regeneration with CO_2. (5)

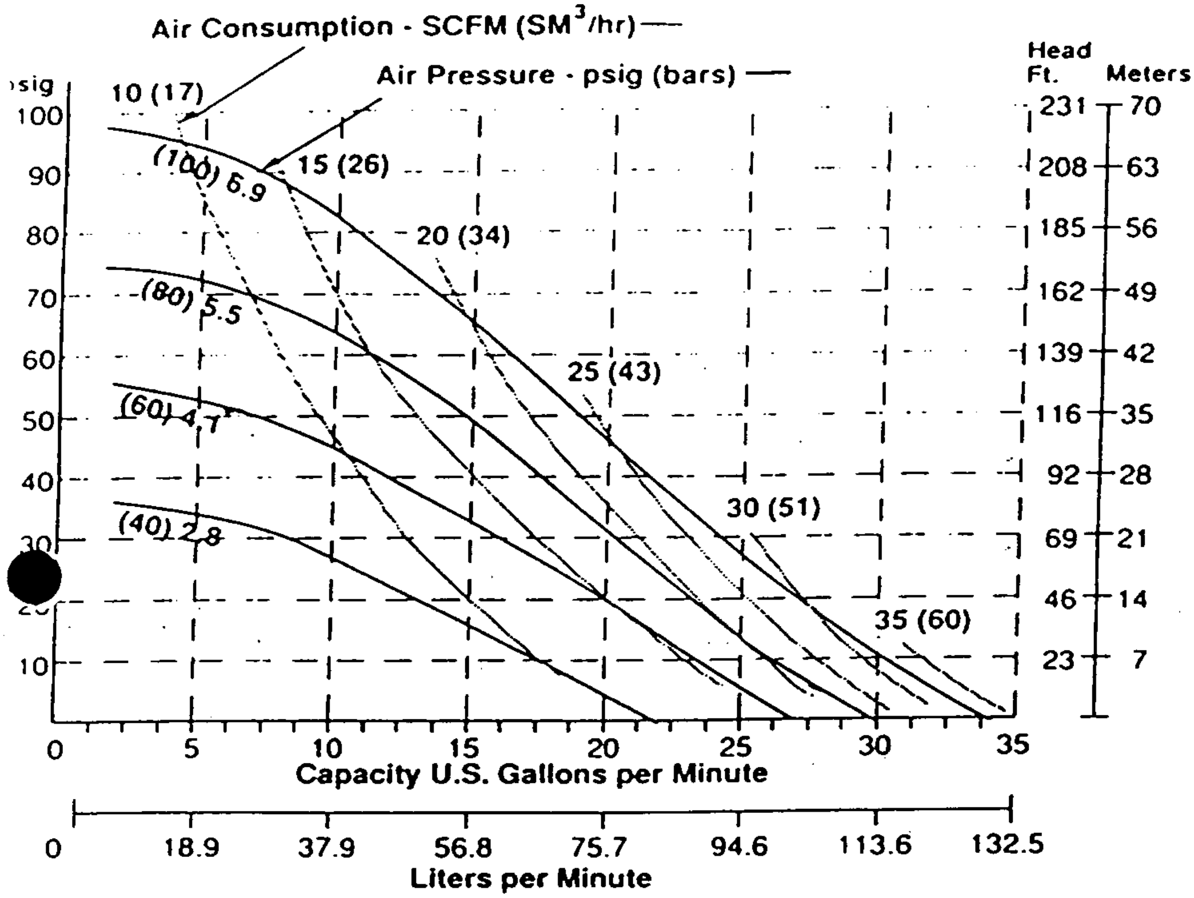
Acknowledgements

Discussions with David Sinclair, Henry Lee, Bruce Cleveland, Dick Hahn and Keith Rowley proved to be invaluable in understanding the measurements done with the test column.

APPENDIX 1:

AMERICAN PUMP BRUTE II: 1" size

Performance Characteristics:



Dimen

Inlet/ C
Air Inle
Maxim
Net W

For pu
your A
Pump.

rformance data based on pumping water with neoprene diaphragms. Capacity is lower
ing Teflon diaphragms. Suction lift capability 15 to 20 ft (4.6 to 6.1 m) depending
ion conditions.

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YOUR AREA DISTRIB

②

2010 l x2 = 4020 l
x .51 g/cm³
≃ 2050.2 kg

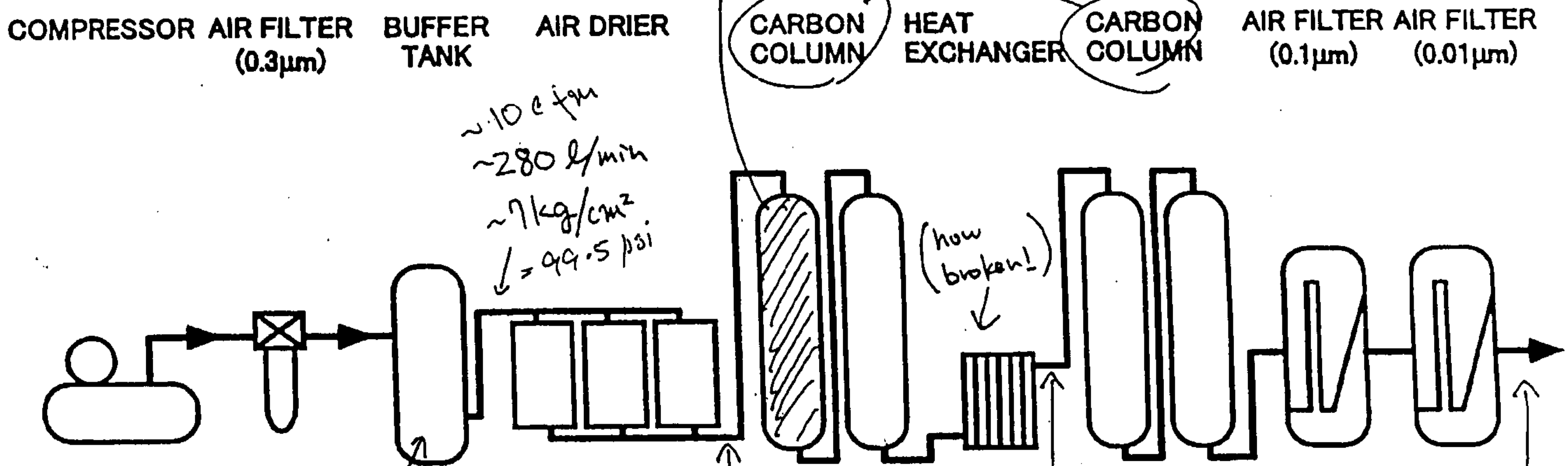
1 sq. in = 6.45 cm²
1 cm² = 0.155 in²

29-AUG-1996
checked by Y. Takeuchi

"TSURUMI COAL, 4GM"
kind of activated chacoal

ϕ800 x H4000
2010 l ⟹ total amount of chacoal = 8040 l
x 2

total about ~~20~~ 16 m long



~0.95 kg/cm²
Flow 10~15 m³/h
16°C

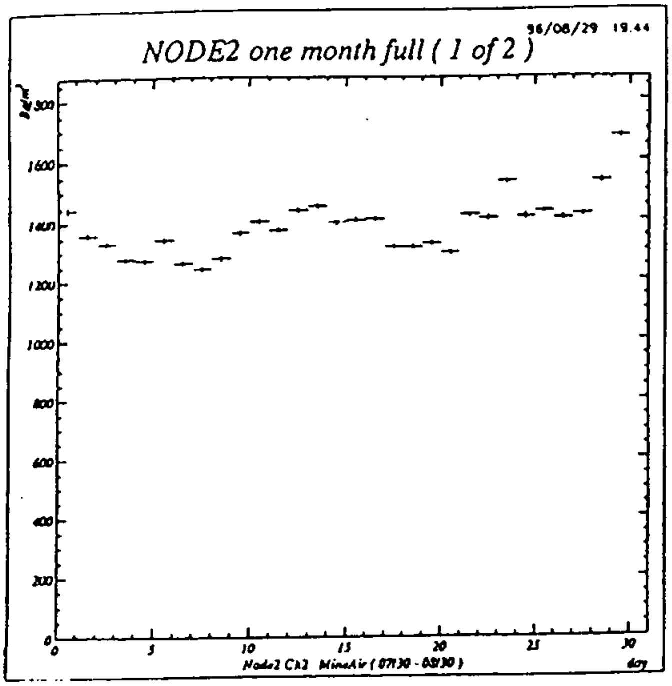
SUPER-KAMIOKANDE RADON-FREE-AIR SYSTEM

≃ 160 lpm
5 cfm

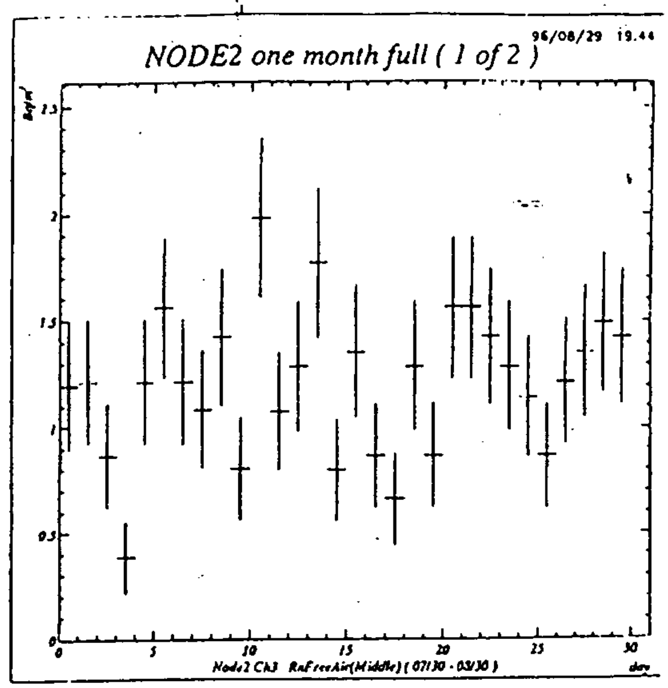
APPENDIX 2: page 1

APPENDIX 2: page2 ③

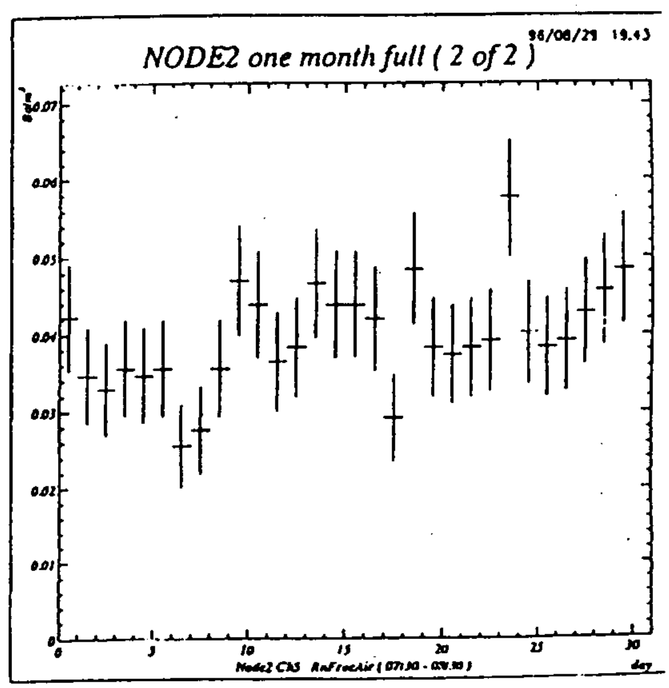
Rn concentration (last 1 month)



INPUT
(before compressor)



MIDDLE
(at heat exchanger)



Rn-Free-Air
(after LAST AIR FILTER).

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