The Engineering of Practical Gas Phase Air Cleaning

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SUMMARY

This is one of two CLIMA 2007 papers on gas phase air cleaning by this author. The Science of Gas Phase Air Cleaning' covers aspects of air quality, gas phase air cleaning (particularly adsorption) limitations and opportunities, capital and energy saving impacts, and the role of Standards.

This paper discusses application parameters, deals with testing of gas phase air cleaners and presents odour removal efficiency test results for a product. Economics of use are discussed.

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INTRODUCTION

The use of gas phase air cleaning (GPAC) in heating ventilation and air-conditioning (HVAC) applications - to remove building/occupant generated pollutants - is rare.

This contrasts with the use of particulate air filters which is near universal.

As indoor air pollutants are either particles or gases this contrast of technology use is stark.

The main barriers to GPAC use in HVAC are:
- Understanding of GPAC
- Product availability
- Testing
- Application approach.

OPPORTUNITY

Presently the HVAC contribution to good indoor air quality (IAQ) is by particulate filtration and use of ventilation to dilute odours (always, for practical purposes, in the gas phase) and other gas phase contaminants like volatile organics.

GPAC use presents the opportunity to reduce ventilation without reducing IAQ.

If ventilation is reduced energy use is reduced, HVAC plant size is reduced, kVA charges are reduced, plant efficiency may be improved, energy infrastructure needs are reduced and greenhouse gas production is reduced – refer to the other paper for more detail.

GAS PHASE AIR CLEANING

Only adsorptive (physisorptive and chemosorptive) air cleaners are dealt with here, as this author sees them as having most potential. Absorptive and (photo)catalytic approaches are not addressed.

Absorptive processes are usually water based, with the obvious problems – humidity control, legionella, chemical contamination of air etc.

(Photo)catalytic media is a possible solution but has the problem that it can sometimes adsorb reasonably harmless chemicals and catalyse them into more harmful species and release these into the airstream (perhaps this problem will be solved by developers).

This author favours adsorption – the pollutant is trapped and held in the media.

Typical adsorptive GPAC ‘media’ are activated carbon, activated alumina, zeolites, silica gel etc. These media may be ‘pure’ or they may be impregnated with chemically active ingredients to allow chemisorption.

A GPAC is usually a bed, of chosen thicknesss, of adsorbent material granules contained between metal mesh or like ‘porous to airflow’ material.

UNDERSTANDING GAS PHASE AIR CLEANING

Adsorption is qualitatively addressed in more depth in the other paper.

Quantitative (mathematical) treatment of adsorption is extremely difficult and the outcomes are exceptionally complex. Also sorbent material performance information is scant.

With application of considerable resources, the matter can be resolved but developed methodologies are largely kept confidential. This author has developed a predictive model. Useful published design recipes are rare, perhaps nonexistent. Industrial adsorption process design seems to be based on considerable experience.

A good (but not simple) overview and basic design data source is Perry’s Chemical Engineers Handbook 7th Edition Section 16 ‘Adsorption and Ion Exchange’.

GPAC BEHAVIOUR

Numerical examination of behaviour of possible and existing adsorptive GPAC’s reveals useful things. Descriptive material addressing adsorption is available – but, without numbers, few useful design conclusions can be drawn.

The efficiency (percentage removal of contaminant from air) of a specific adsorptive bed at a specific time depends on many factors - including contaminant concentration, contaminant nature, adsorbent nature, face velocity, temperature, effect of other contaminants, bed depth.

The actual proclivity of a sorbent to sorb a contaminant is paramount but after this the prime characteristic of interest, when considering performance of practical GPAC units, is depth of the media bed (dimension in the direction of airflow). This can be qualitatively referred to by calling these beds ‘thick’ or ‘thin’.

Media bed depth is not to be confused with the overall size of a commercial GPAC. Such units are often composed of thin sub units arranged in ‘v’, ‘w’, etc formation so that much media face area is presented to the airflow. These composite units thus have a large dimension in the direction of gross airflow but the individual sub units have a smaller dimension in the direction of local airflow.

Variation, over time, of efficiency is particularly dependent on bed depth. This is now addressed, but in a simplified manner.

When presented with a substantially constant pollutant removal challenge a thick bed GPAC operates thus:

- At air inlet side of the bed there is part of the bed thickness (say ¼ of the thickness – as an aid to thinking) referred to as the mass transfer zone
- As air moves through the zone the pollutant concentration decreases until it becomes the practical minimum at the end of the zone (i.e. practically, as clean as it is likely to get – often close to 100% pollutant removal)
- As time passes, and more air is cleaned, the upstream part of the zone becomes increasingly saturated with pollutant and the downstream edge of the zone moves further downstream
- As more time passes the bed divides into three zones – an increasingly wide saturated zone, followed, by a largely constant width mass transfer zone and a increasingly smaller ‘clean’ zone
- The mass transfer zone may widen or narrow as it moves, depending on the adsorption relationship, A narrowing zone will asymptotically approach a constant width.

The practical outcome of the above is that a thick bed GPAC will have a substantially <u>constant pollutant removal efficiency</u> for a period of time and then this efficiency will decrease. Finally, when the bed is saturated the efficiency will be zero.

If a thin bed GPAC is used (i.e. the thickness is less than that of the mass transfer zone - the ‘critical thickness’) then the initial <u>efficiency</u> will be a chosen value and it <u>will decline from the time of first use</u>. This is usually an undesirable characteristic.

REQUIRED GAS PHASE AIR FILTER PERFORMANCE FOR HVAC

Example (typical in many places) HVAC conditioned airflow into an occupied space is about 50 litres per second per person (l/s/pp) – this is determined by thermodynamic needs i.e. it is the airflow required to deliver the required heat (or “coolth”).

Typical “fresh air” flow into a space is about 10 l/s/pp – this is what is needed to maintain odour at acceptable levels – given conventional design practice.

Say 7.5 l/s/pp of this fresh air is replaced by recirculation air that has been 100% cleaned in a GPAC. And, also, that 2.5 l/s/pp of "fresh" air is delivered to dilute CO_2 and other pollutants etc to acceptable levels. In this scenario the 10l/s/pp of ventilation air is replaced by 2.5 l/s/pp of ventilation air plus 7.5 l/s/pp of cleaned air with the cleaned air being, in the case of many pollutants, cleaner than the ventilation (outside) air that otherwise would have been used.

Now, consider that the same outcome is to be achieved by use of a GPAC treating all conditioned air flow (i.e. 50 l/s/pp). The question arises "what is the required efficiency of this GPAC".

The answer: 7.5/50 or 15%. i.e. the required gas phase air cleaner odour removal efficiency is 15%. The required efficiency would be 10% if 5 l/s/pp was cleaned.

So, the required efficiency of a GPAC used for odour control in reasonably normal HVAC systems will be in the order of 10% to 20%.

AVAILABLE GAS PHASE AIR FILTER PRODUCT

Presently GPAC product is available for HVAC application. Mostly this product contains activated carbon or potassium/sodium permanganate impregnated activated alumina. A wide range of other impregnations (for carbon and alumina), including some with catalytic activity, are also available.

Generally, the % efficiency of this product (at any stage of its operational lifecycle) for removal of odours, or many other pollutants, will not be stated by the manufacturer.

Designers must rely on their experience etc and, perhaps, their 'blind faith'.

Most of this presently available commercial product is, in the context of claimed HVAC use for the removal of body odours etc and trace organics, thin bed. There is a small amount of thick bed product available but it seems to be aimed at industrial use.

This product will thus, generally, offer pollutant removal performance that will decline (from what value?) immediately and continuously, or soon and then continuously, after installation.

The presumed reason for one aspect of this undesirable situation is that a GPAC user must limit the air pressure drop to that he/she finds acceptable and GPAC manufacturers provide product to match this presumed requirement.

At the heart of this issue is the balance that must be made between the advantages to be obtained by GPAC use in HVAC (lowered ventilation, plant size, energy use etc) and the costs – particularly fan energy use. In some cases the problem is illusory, in most it deserves attention.

An optimal approach to many, if not most, practical situations is to be found in a recent Patent application[1].

GPAC TESTING

A user of GPAC properly requires adequate performance data – though, to date, much use has been with rule-of-thumb design methods or pure faith.

GPAC may be used to remove pollutants that are undesirable from a health or like perspective. They may also be used to remove odours from air.

As many ventilation standards/requirements are based on odour control (with a smaller ventilation rate set for health reasons) e.g. Australian Standard AS1668.2: 2002[2], the major opportunity for economic application to HVAC use is in odour control – though VOC etc control is of importance.

A number of organisations (ASHRAE, ASTM, CETIAT etc) and some companies have done thorough and advanced work in the development of standards and apparatus for testing the removal efficiency of GPAC or GPAC media for specific chemicals – e.g. toluene.

If theory and data collection were sufficiently advanced then information from such testing may be applicable to calculation of odour removal by GPAC. However, it seems that we are presently a very long way away from this goal.

Accordingly, it is desirable that GPAC be directly tested for odour removal efficiency.

GPAC ODOUR REMOVAL EFFICIENCY TESTING

This author has developed GPAC odour removal efficiency test apparatus (a test rig) at the Australian National University. This apparatus is suited to the testing of full scale GPAC product. The apparatus is designed to test GPAC so that they may be used to gain 'outdoor air' concessions in accordance with the requirements of AS1668.2[2] (1991 and 2002 editions). Product has been successfully tested.

The mentioned test rig is believed to be the only one in operation or under consideration – anywhere. The test approach is now described.

Odour removal efficiency removal testing requires the use of human noses. Current sensor technology is not up to the task. The described methodology uses human odour assessors.

Traditionally, in respect of olfactory assessment of indoor air, there has been debate about whether assessors are to be (a) selected for olfactory capability or selected as being representative of the general population and/or (b) trained or untrained. Assessors selected for testing of devices in accordance with the methodology <u>are selected</u> for adequate olfactory capability and <u>may or may not</u> be trained for the specific or general task at hand. Assessors are selected in accordance with AS2542.1.3[3].

The method is conceptually straightforward:

- A panel of assessors samples two air streams and declares which is the most odorous
- In olfactory science terms this is a bilateral paired comparison test in accordance with AS2542.2.1[4] (tests other than the bilateral type may be chosen)

- Contaminated air is drawn from an enclosure reasonably representative of one for which the GPAC may be used (eg a nominated type of air-conditioned room with people in it)
- "Fresh' air is drawn from outside. Source/treatment conditions are specified
- Cleaned air is drawn from downstream of the GPAC
- A minimum GPAC odour removal efficiency is postulated
- A mixture of contaminated and fresh air (chosen to mimic air that has been cleaned by a GPAC of the postulated efficiency) is delivered to assessors
- Cleaned air is delivered to assessors
- The two airstreams are assessed and the most odorous is declared
- If the cleaned air is less odorous than the mixed airstream then the minimum efficiency of the GPAC (in the tested application) is as postulated
- The test is repeated, at a different postulated minimum efficiency, if required.

In operation the test rig has proved to be robust, efficient and effective.

The rig has few limitations, and these will be soon remedied. Presently the rig will only test a postulated efficiency up to a level just above 90%. At higher efficiencies one airflow falls outside the parameters of the airflow test measurement standard used (AS 2360.1.1: 1993[5]).

TEST RESULTS

A GPAC device for the removal of body odour and other building occupancy odours (established building) has been developed. The composition of the media bed is proprietary (a trade secret).

The GPAC has been tested. It has a minimum tested body odour etc removal efficiency of 90.4% with $P<=0.05$ error probability (criteria that is customary in sensory science, and other scientific and engineering applications). The calculated actual efficiency is in excess of 98%.

ECONOMICS

The economics of GPAC use to reduce ventilation costs is illustrated in the following table. Here the savings to be made by GPAC use for 14 Australian cities are tabulated. The calculations have used precise hourly outdoor dry/wet bulb frequency data. The cities represent most climate types but no really cold climate is represented so conclusions cannot be drawn for many north American and north European places. Note that the estimated savings in the table below are based on energy use at Australian prices. European prices are considerably higher.

Next table below assumes:

Ventilation rate reduction: 1000 litres/second (perhaps a 200 person building)
Cost of electricity for cooling: A$0.138/kWH, Cooling coefficient of performance: 3.0
Heating gas energy cost: A$0.0372/kWH, Heating system efficiency: 76%
Marginal capital cost of cooling effect: A$800/kW
A$=Australian dollar (in early 2007, A$1.0~0.6 Euro~USA$0.8)
6am to 6pm, 6pm to 6am or 24hr operation: 24C summer inside, 21C winter inside.
Economy cycle not used, no humidification, dehumidification only to 60% RH.

Australian City	*Climate*	*Marginal cooling plant cost (A$)*	*Annual cool+heat cost, day (A$)*	*Annual cool+heat cost, night (A$)*	*Annual cool+heat 24 hr (A$)*
Adelaide	Mediterranean	12,480	887	1290	2077
Alice Springs	Hot arid	15,440	1644	1461	3104
Brisbane	Sub tropical	18,240	1417	847	2264
Canberra	Temperate	4,880	1565	2406	3970
Cloncurry	Semi arid tropical	16,080	2622	1751	4373
Darwin	Monsoon	21,280	5011	4350	9361
Hobart	Cool temperate	3,040	1274	1913	3187
Melbourne	Temperate	10,160	1020	1511	2531
Mildura	Semi arid	14,880	1171	1531	2710
Perth	Mediterranean	12,096	893	978	1870
Port Hedland	Semi arid	15,360	3609	2603	6212
Sydney	Temperate oceanic	6,800	1018	1973	2991
Townsville	Wet tropical	25,680	3603	2405	6008
Wagga Wagga	Temperate	12,560	2224	1706	3930

The operation cost (media+energy) of the mentioned 1000 l/s unit, used as shown in reference 1, is likely to be in the region of $A1000 per annum for a typical office space (2500 hrs/year) use. The capital cost is not given here.

Clearly, GPAC use is cost effective in many climates. In many places it is cost effective in capital cost terms regardless of energy savings. It may be used only or principally to reduce capital and kVA etc. charges - thus reducing GPAC fan energy to negligible levels and extending media life to, perhaps, decades.

CONCLUSION

Now is an opportune time for the widespread introduction of gas phase air cleaners into HVAC applications. Various monetary savings and environmental benefits can be had worldwide. There is present ample opportunity for interested commercial entities to leverage recent developments into benefiting the greater good through improving indoor air quality and reducing greenhouse gas emissions.

REFERENCES

1. A reference to the USA application is: [www.fresh**patent**s.com/Method-and-device-for-cleaning-air-dt20060413ptan20060078480.php].
2. Australian Standard 1668.2: 2002: Standards Australia, www.standards.com.au.
3. Australian Standard 2542.1.3 : Sensory Analysis Method 1.3: General guide to methodology - selection of assessors.
4. Australian Standard 2542.2.1: Sensory Analysis – Paired comparison test.
5. Australian Standard 2360.1.1: Measurement of fluid flow in closed conduits Part 1.1: Pressure differential methods – Measurement using orifice plates, nozzles or venturi tubes – conduits with diameters from 50mm to 1200mm.