PRESSURE SWING ADSORBTION (PSA) REGENERATIVE CHEMICAL FILTRATION AND ENVIRONMENTAL CONTROL SYSTEMS FOR THE COLPRO OF ARMOURED FIGHTING VEHICLES

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Carbon-based adsorbtion systems have long been used for the provision of COLPRO, including the protection of personnel in armoured fighting vehicles. Charcoal systems are not only unable to provide the broad band protection levels required by emerging threats but being disposable, would result in an unacceptable logistic burden in the event of a chemical war.

PSA-based systems have been shown to provide both the necessary broad band protection against a wide range of chemical hazards under the most difficult environmental conditions and to be fully regenerable removing the need for chemical filter replacement.

INTRODUCTION

Aircontrol Technologies, as one of the U.K's leading authorities in the design and integration of NBC and Environmental Control Systems in armoured vehicles, and PALL Aerospace, experts in the design of filters of all types including those employing PSA principles, have jointly developed a PSA based system which has been subject to trials both in an armoured personnel carrier to demonstrate vehicle integration, and as a full scale laboratory system for agent testing at Dstl, the British MoD's Bio-Chemical Research Establishment, Porton Down, England.

This Paper describes this work and the background research carried out in support of it.

1. The Threat

Before establishing the most appropriate technology for a new protection system, the threat must be considered.

In the case of nuclear weapons, NBC systems address only the prevention of the contamination of the crew space and injestion by the crew of radioactive dust. As with dust, biological agents can be considered as small particles and can, therefore, be removed from the supply air using fine particulate filters.

This technology is well understood and when combined with an effective method of chemical agent removal, will provide very high levels of protection from NBC threats.

Current threat assessment for chemical agents have identified potential threats from a broad band of chemicals, some of which fall outside the capability of current charcoal systems to provide protection. New technology must therefore be able to provide protection across the full spectrum of practical chemical weapons. This required a system that will be effective against all gases with boiling points of between -84°C to +230°C (-120°F to +450°F).

In addition, the filters should be able to resist repeated attacks and be fully regenerable. As water boiling point falls within the target range, any system must be able to adsorb and regenerate very substantial quantities of water vapour when operating in hot humid geographical areas.

2. Considered Technologies

To enable the required broad band protection to be offered for the next generation of fighting vehicles, it was deemed necessary to select a base technology that could both achieve the protection levels and that was mature. For these reasons, technologies such as catalytic oxidation, selective membrane, corona discharge and plasma were rejected in favour of sorbtion systems.

Sorbtion technologies capable of being regenerated can be classified by the method used to drive off the gases adsorbed, these are:

- Temperature Swing Adsorbtion (TSA)
- Pressure Swing Adsorbtion (PSA)
- Pressure and Temperature Adsorbtion (PTSA)

All these systems use a minimum of two filter beds, one adsorbing while the other is 'Regenerating' by the removal of previously adsorbed challenges. Following regeneration, the incoming air is diverted to the cleaned bed and the bed previously 'on line' commences its regeneration cycle.

All systems must be designed so that the on line bed cleans a quantity of air, in excess of that required for COLPRO, the balance used to purge the desorbed gases in the regenerating, off line filter bed.

3. Temperature Swing Adsorbtion

A TSA system is similar to current charcoal systems in that it removes gases at low (ambient) pressure, but is then regenerated by heating the regenerating bed to temperatures in the order of 170°C (338°F). The regenerated bed must be fully cooled before it can be used on line and unlike current systems, the adsorbent material cannot be treated to improve the range of chemicals adsorbed as such treatments would be destroyed during the regenerative heat cycle.

4. Pressure Swing Adsorbtion

In the case of a PSA system, the on line bed operates at an elevated pressure and the off line bed regenerates at low pressure. The beds being designed to adsorb gases at elevated pressure, the gases are released when the pressure is removed.

5. Pressure Temperature Swing Adsorbtion

PTSA systems combine the characteristics of both TSA and PSA systems in that adsorbtion takes place at elevated pressure and desorbtion is achieved by removal of the pressure and heating of the bed.

6. Selected Technology for Vehicle COLPRO Systems

The need to heat up the off line bed to 170°C (338°F) and to cool it down to below 70°C (158°F) before it can be put on line, typically requires in the order of 45 minutes. As a result, the on line bed must be able to provide full protection for this length of time. Many of the emerging threats, including many TICS and TIMS have low boiling points which are only weakly adsorbed and will break through the on line bed within the timescale of a bed of practical size.

The need for a very large bed capacity eliminates TSA as a practical solution for vehicle COLPRO.

As the change from one bed to the other is nearly instantaneous, PSA systems can operate on very short cycle times, in the order of 10 to 20 seconds, therefore the filter beds are small and are effective in retaining light gases. However, pressure change is not fully effective in the removal of all high boiling point chemicals.

PTSA overcomes the potential problems of desorbtion of high boilers at the expense of bed size and protection against low boilers, due to the heat cycle used to assist desorbtion, imposing the same cycle times as for TSA systems.

Of the above base technologies, only PSA was considered to offer a basis for a practical regenerative system for vehicles and that the potential problems of some bed retention of high boiling point chemicals could be addressed by a periodic bed clean up with a heat cycle. This new technology being described as PSA + T.

Adsorption system technologies considered			
System type	Broad band protection	Typical cycle time (min)	System bed sizes
Low pressure temperature swing (TSA)	Poor	30/45	(1), (2) V large
High Pressure temperature swing (PTSA)	Potentially V good	30/45	(2) V large
Pure pressure swing (PSA)	V good	0.16/0/33	(3) Small
Pure pressure swing – with final decontamination heat cycle (PSA + T)	V good	0.16/0.33	Small

Notes
1. Does not provide broad band protection
2. Too large for practical vehicle COLPRO applications
3. Some vapour remains locked in beds – possible long-term hazard

Figure 1.

7. Vehicle System Design

A typical PSA system for vehicle NBC COLPRO is shown at Fig 2.

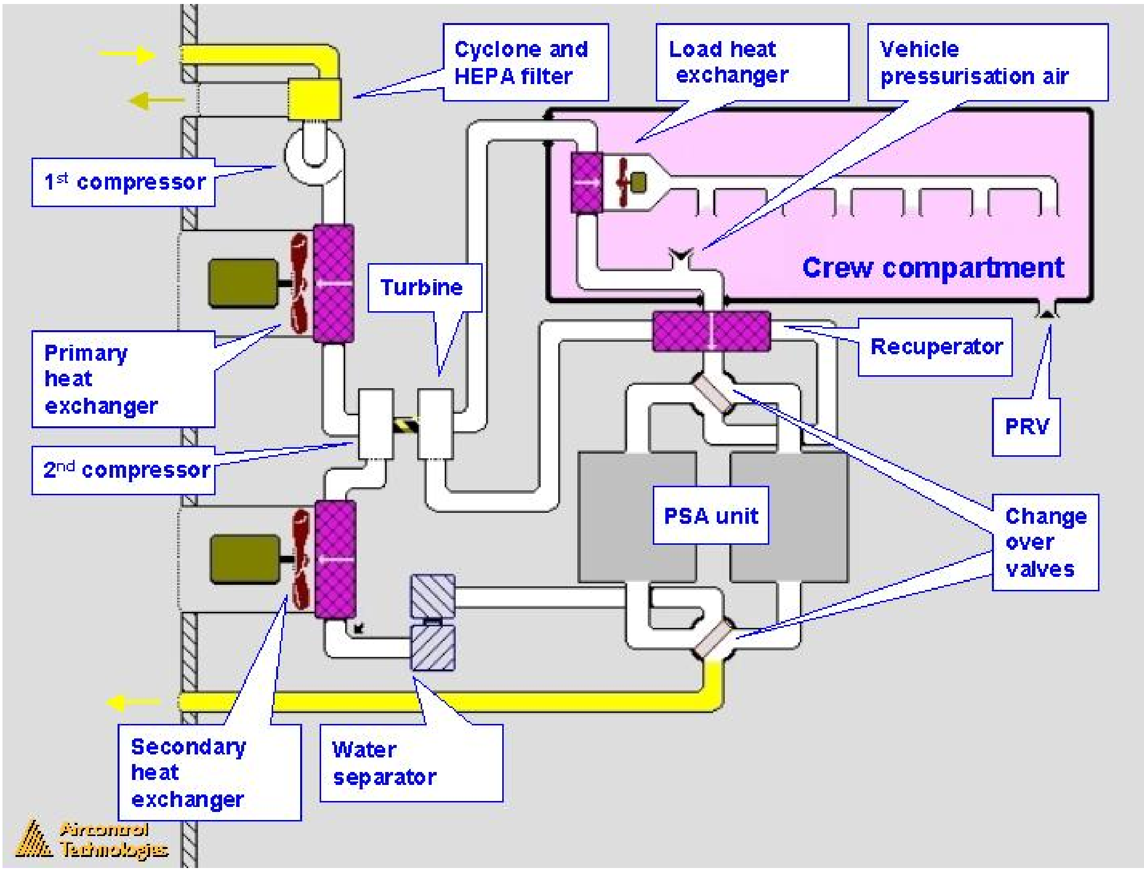

Figure 2.

Air is drawn into the system through a high efficiency cyclone filter which removes the major dust burden, and then through a high efficiency particulate filter which removes fine dust particles and biological material before entering the first stage compressor which provides the necessary process airflow to provide both the required product and purge airflow and the required initial pressure to drive the PSA system. In the case of the system demonstrated, this was a total of 340m³/h (200CFM) to provide 170m³/h (100CFM) of usable product air with an initial pressure of 1.8bar g (25.6 p.s.i). Following initial pressurisation and reduction of the heat of compression in the primary heat exchanger, the air passes into the secondary compressor where it is raised to required bed operating pressure of 3bar g (42.6 p.s.i) following which, the heat of compression added to the air is again reduced as it passes through the secondary heat exchanger, and having passed through a coalescer to remove any condensed free water, enters the on line bed.

The cleaned air, still at high pressure, passes through a recuperator where it is cooled, before being expanded through the turbine down to near ambient pressure. The turbine expander has a dual function, the high pressure air entering drives the secondary compressor as it expands so that the recovered energy is used to produce the secondary compressor pressure boost and in doing this, gives up energy in the form of heat and leaves the turbine as cold air.

The cold air source can be used to cool the vehicle crew as shown in Fig 2, both by indirect means and by its release into the crew compartment to provide the required ventilation rate and COLPRO overpressure which is controlled by a Pressure Relief Valve (PRV). The remaining processed air passes through the recuperator pre-cooling or heating the air leaving the on line filter, before entering the off line filter and purging it of desorbed gases. In addition to air cooling, the heat of compression can be used for heating so the PSA system can supply a source of both cooling and heating using waste energy to provide an integrated environmental control system.

8. Qualification of the Filter Bed Technology

To establish the bed design and to demonstrate that it meets the requirement by testing with both live agents and simulants, a contract was placed by PALL Aerospace with Dstl, Porton Down.

In addition to achieving the required broad band protection and regenerability, the requirement was for this to be achieved for the minimum power budget (process airflow and pressure) and to ensure the bed performance was such that the final + T clean up cycle was not operationally necessary.

9. Bed Development

Development was carried out on $1/40^{th}$ scale beds using both simulants and live agents.

It is critical in establishing the performance of a system that this is carried out as it then enables full size beds where the use of live agents is undesirable, to be tested with simulants so that, by ensuring that the simulants performance is the same on both model and full size beds, the scaling effect can be proved and hence the protection against live agents can be read across.

The beds were repeatedly challenged, without any + T clean up cycle, under B_3 STANAG 2895 hot wet environmental conditions to simulant the most challenging environmental conditions, with no detectable breakthrough. The mass uptake of vapour was tracked and it was confirmed that at a mass of approximately +10% of bed weight, stable conditions were achieved. See Fig 3.

	Agent/ Simulant	Challenge Ct (mg min m^{-3})	Mass Challenge (g)	Cumulative Mass Uptake (g)
Challenge Results B3 (Humid Hot Coastal Desert) Conditions Includes coastal Areas of the Gulf States. Challenge level 35°C 32°C dp can occur for up to 6 hours of the Diurnal Cycle	F23	33,000	2.3	-
	F23	110,714	7.75	-
	F23	93,571	6.55	12.0
	F23	63,857	4.47	-
	AC	81,571	5.71	-
	CK	92,000	6.44	12.5
	F23	97,143	6.80	-
	F23	75,082	5.26	-
	F23	69,617	4.87	13.0
	F23	79,126	5.54	-
	F23	37,923	2.65	-
	AC	84,371	5.91	-
	AC	45,803	3.21	
	F23	38,470	2.69	-
	F23	59,782	4.18	-
	AC	118,579	8.30	-
	AC	116,175	8.13	13.0
	CK	90,601	6.34	-
	CK	49,946	3.50	13.0
	PFIB	40,765	2.85	-
	F23	43,060	3.01	13.0
	F23	63,607	4.45	13.0
	HFCB[b]	125,028	8.75	13.0
	HFCB[b]	83,497	5.84	13.0
	HFCB[b]	50,273	3.52	13.0
	Isobutene	89,833	6.29	-
	134a	120,214	8.42	13.0
	134a	76,500	5.36	-
	Octane	126,756	8.87	13.5
	Octane	81,708	5.72	-
	Ethanol	125,924	8.81	-
	Ethanol	82,595	5.78	14.0
	2CEEE	124,119	8.69	14.0
	2CEEE	82,400	5.77	-
	PS	126,143	8.83	-
	PS	82,508	5.78	14.0
	Avtur	127,557	8.93	18.5
	Avtur	82,605	5.78	19.0
	DMMP	125,319	8.77	18.5
	F23	82,054	5.74	18.0
	DMMP	81,297	5.69	18.0
	F23	80,757	5.65	17.5

Figure 3.

10. Vehicle System Development

Following the establishment of the filter bed operating requirements, the vehicle system components were defined. For the prototype vehicle demonstrator and simulant test rig, where possible, commercial components were adapted to achieve the required performance. This included the primary compressor (screw type) and the use of a modified vehicle turbocharger as the secondary compressor/expander.

The GFE vehicle supplied for trials was a 1960's vintage armoured personnel carrier, and the requirement was to integrate the regenerable NBC system in the vehicle without affecting its ability to carry a compliment of 10 soldiers plus the Driver and Commander. The space available for the system is shown at Fig 4.

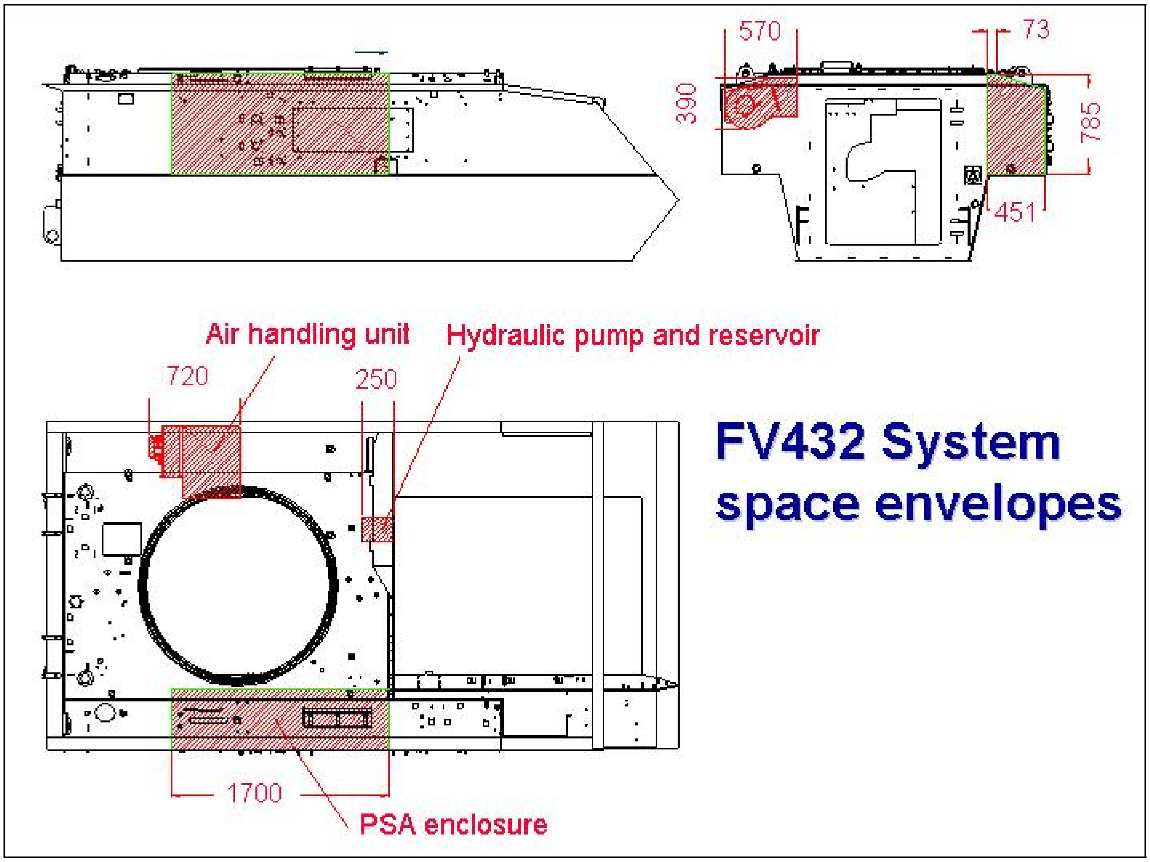

Figure 4.

The NBC system must provide a constant flow of clean air to provide COLPRO in the crew compartment and so the primary compressor should preferably run at a constant speed. To achieve this from constantly changing speed of the vehicle engine, a hydraulic drive system was used. The variable swashplate pump fitted to the engine gear box supplying a constant hydraulic fluid flow to the primary compressor motor, controlling its speed to within ±5% over the full range of engine speeds. The system component layout is shown at Fig 5.

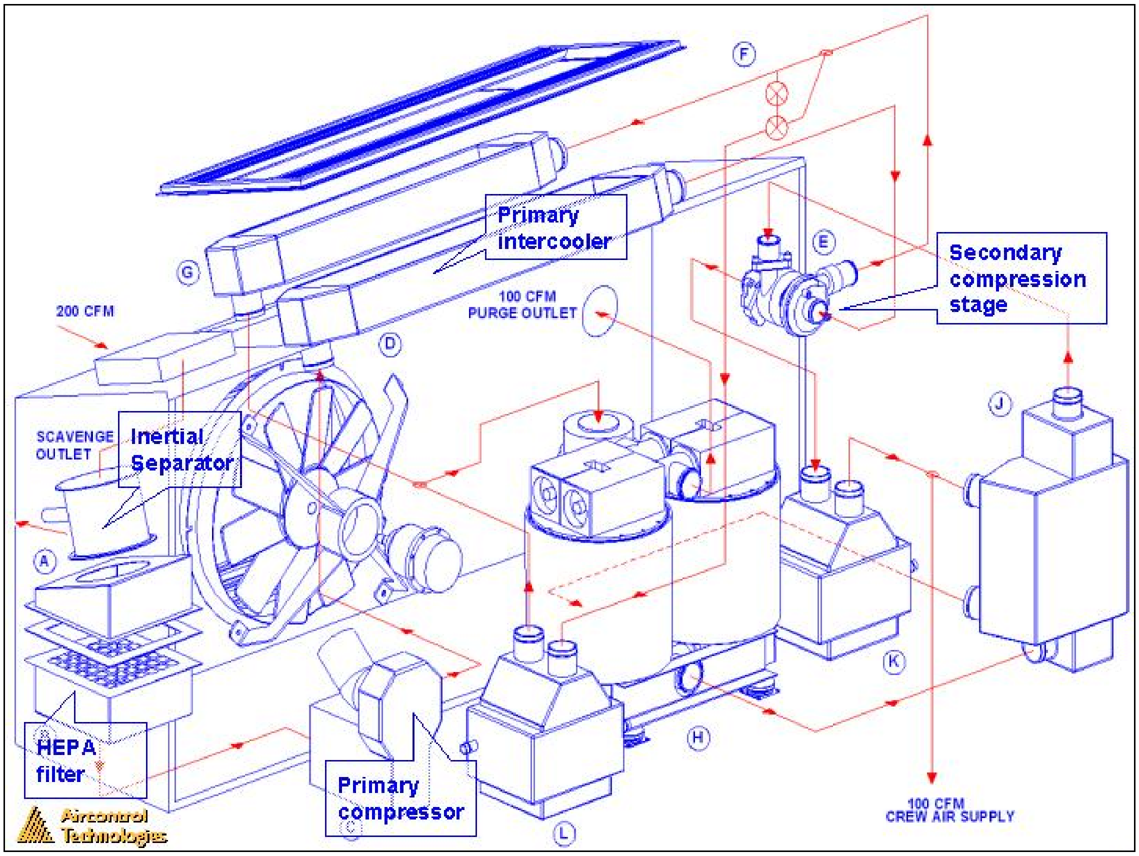

Figure 5.

It can be seen that the Crew Temperature Control System makes use of secondary water glycol liquid circuits which are then pumped to an Air Handling Unit. This is necessary as the cold air produced from the recovery of energy when expanding the process air through the expander is significantly sub zero over much of the operating conditions and this would rapidly ice up any simple air to air heat exchanger. In addition, the hot air created by compression may be contaminated.

The laboratory test system was constructed using the same basic components as the vehicle system but for convenience was driven by a 2-pole 3-phase electric motor.

Figure 6.

CONCLUSION

Following testing, the PSA+T system developed jointly by Aircontrol Technologies and PALL Aerospace has shown:

- There is no filter penetration even in pure PSA mode and very high mass challenges.
- The filtration bed can be frequently challenged without loss of performance/protection.
- Little material is retained by the bed.
- Retained material doesn't accumulate after successive challenges.

When challenged with agents having boiling points from -84°C to +230°C.