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Title OIL REMOVAL SYSTEM DESIGN

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OIL REMOVAL SYSTEM DESIGN

PROBLEM:

TITLE

. To design an absolute oil removal system for the ESCAR 1500 watt helium refrigeration compressors, for flow of 3000 SCFM at 18-20 atm, pressure drop and costs are to be minimized; service life 7000 hours.

FIRST APPROACH:

Design by standard procedures using empirical data for fiberglass filters, and sorbates.

Pressure drop data for air at 1 atm is corrected to Δp for He at 18 atm by density ratios applied to:

$$\Delta P = f \frac{L}{D} \int \frac{V^2}{2g} \qquad \frac{\Delta T_{AVL} - left_{M}}{\Delta P_{He} - l8} \simeq \frac{P_{AlW} - l}{P_{He} - l8} = \frac{P_{AlW} - l}{P_{He} - l8}$$

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Filter collection effeciency is assumed equal for all cases in the first approximation. If diffusion effects are predominant then possibly the diffusion equation may apply.

 $N_A = -D \frac{\partial c}{\partial s} \dots$ page 538, "Chem. Eng. Handbook", 3rd Ed. 1950

 N_A = lb-moles of component A diffusing per hr. ft.²

 $\frac{\partial c}{\partial s} = c$, concentration, lb-moles/ft.² s, distance, ft.

D = diffusion coefficient - ft.²/hr. or cm^2/sec .

$$= K \frac{T^{3/2}}{P(\mu_{a}^{1/3} + \mu_{b}^{1/3})} - \sqrt{\frac{1}{M_{1}} + \frac{1}{M_{2}}}$$

M = mol. wts. of gases * = mol. vol. @ n.b.p. \mathbf{P} = pressure, atm T = temp., °K.

At first glance, the P factor is predominant and for diffusion effects:

$$\frac{\stackrel{D}{\text{He}} @ 20 \text{ atm}}{\stackrel{D}{\text{air}} @ 1 \text{ atm}} \sim \frac{\stackrel{P}{\text{air}} \frac{1}{20}}{\stackrel{P}{\text{He}}}$$

or efficiency data for 1 atm air is 20 times better than He at 20 atm.

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However, intuitively the coalescing process is improved by lowering the temperature. The particle mobility is slowed so that the sticking factor is better?

Then: $\frac{D}{D_{air}} \simeq \frac{P}{P_{He}} \left(\frac{T}{He} \right)^{3/2}$

and lowering the temperature and raising the pressure should improve the coalescence.

First approach design is discussed further in:

EN 4313-03 M51 "72" Bubble Chamber Aerosol Removal"-R. Byrns, Nov. 1960.

M 4903 "ESCAR Refrigeration System Fiberglass Filter Design," S. Mitina, Feb., 1976.

M 4904 "ESCAR Refrigeration System Charcoal Adsorbant Design," S. Mitina, Feb., 1976.

SECOND APPROACH:

Use as a <u>model</u> a commercial helium compressor package. This consists of a two-stage reciprocating Freon compressor modified for helium with full oil injection as coolant and lubricant, and an absolute oil removal system. The oil injection provides an approach to isothermal compression and permits high compression ratios per stage. The oil used was a synthetic, polyalkalene glycol, UCON-LB-400-X. The X series contains a standard aromatic amine antioxidant, amyl aldehyde, which easily passed thru the system charcoal adsorbant. It then stopped in the low-temperature internal purifiers and was later released (chromatographic) to stop in the expander engine valves. The ''X'' additive is no longer purchased and only LB-400 is used. Otherwise the oil removal system works well for continuous periods up to 8000 hours.

The model flow is 60 SCFM (4.6gm/sec) first stage pressure \sim 30 psig; second stage \sim 235 psig, and oil pump pressure 60 psig. Pressure drop from second stage discharge to the exit of the oil removal system is \sim 10 psig.

The oil removal system consists of an aftercooler, float trap, bulk oil separator, demistifier and adsorber. Estimated removal and ΔP are shown in Fig. 1. Page \Im

Model flow is 60 SCFM at 15-18 atm. Our prototype flow is 3000 SCFM at 17-20 atm

Scale Factor (S.F.) = $\frac{3000}{60}$ = 50.

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By first approximation we could put 50 of the model units in parallel for a satisfactory solution, (or use the same superficial velocity and bed depths.)

Our prototype compressor will be vendor supplied with a bulk oil separator of three stages, a 30" dia. thak for initial liquid/gas gravity separation, a metallic mesh disentrainer, and a fiber with exit delivery approaching 200-300 ppm.

RL-3220-2a(Rev.8/71)

EINGINEERING NOTE ESO 510 May 3 1 R. Byrns Mechanical Engineering Berkeley 18 February 197 COALESCER: A coalescer stage is needed. The model (Fig. 2) internals are unknown but assumed to be fiberglass. $D_{m'}$ diameter of model, is 8" Model $V_s = \frac{Q}{A} = \frac{60 \text{ SCFM}}{\frac{17}{4} - \left(\frac{8}{12}\right)^2 17 \text{ atm}} = \frac{3.55 \text{ ACFM}}{.348 \text{ ft}^2} = 10.2 \text{ ft}$./min. Prototype $V_s = 10 \text{ ft}$./min. $= \frac{3000}{18 \cdot A}$: A = 16.7 ft. $^2 = \frac{17}{4} D_p^2$; $D_p = 4.65 \text{ ft}$. = 56" First approximation is a pressure vessel of 56" dia. with stages of fibergla .Other geometries can be used to obtain $A \simeq 16 \text{ ft}$. 2 with a smaller, m economical pressure vessel, such as Pall reverse "Ulti-Por" multiple unit t - 5 ft. each. (of HANKINKON) "Att $2 Lifter EX$ (or EAUSTON.) concepted (HARCOAL ADSORBER. (Fibure 3) $\nabla^{ach} = 2 \text{ ft}$. $\frac{166 \text{ ft}}{18 \text{ thm}} = 6.75 \text{ ft}$ Model $V_s = \frac{60}{4 \text{ the struct}} \text{ ft} \frac{1000}{16} \text{ the struct} 1000$	LAWREN	CE BERKELEY LABORA	TORY - UNIVERSITY	OF CALIFORNIA	CODE	SERIAL	PAGE
R. ByrnsMechanical EngineeringBerkeley18 February 19:COALESCER:A coalescer stage is needed. The model (Fig. 2) internals are unknown but assumed to be fiberglass. D_m , diameter of model, is 8"Model $V_s = \frac{Q}{A} = \frac{60 \text{ SCFM}}{\frac{TT}{4} - \left(\frac{8}{12}\right)^2 17 \text{ atm}} = \frac{3.55 \text{ ACFM}}{.348 \text{ ft.}^2} = 10.2 \text{ ft. /min.}$ Prototype $V_s = 10 \text{ ft. /min.} = \frac{3000}{18 \cdot \text{ A}}$; $A = 16.7 \text{ ft.}^2 = \frac{T}{4} \text{ D}_p^2$; $D_p = 4.65 \text{ ft.} = 56"First approximation is a pressure vessel of 56" dia. with stages of fibergla.Other geometries can be used to obtain A \simeq 16 \text{ ft.}^2 with a smaller, meconomical pressure vessel, such as Pall reverse "Ulti-Port" multiple unit\sim 5 \text{ ft.}^2 each. (pR HANKINSON, "ASA DUSCET,") or ZAUSTON. concessesCHARCOAL ADSORBER.Model diameter is 6"Contact time, T = \frac{2 \text{ ft.}}{18 \text{ ft.}^2} fm.\frac{1000}{m} = 6.75.Model V_s = \frac{60}{2}\frac{60}{2} 217 \text{ atm}\frac{7T}{16}\frac{60}{2}Prototype V_s = 18.1 \text{ ft.}^2 fm.\frac{1000}{m} = 3.28 \text{ ft.} = 39.4"Model tharcoal bed depth is 24^{\circ}; (9.3)(2) = 18.6 \text{ ft.}^3\frac{1000}{2} \text{ ft.}^232 (18.6) = \frac{596 \text{ 158.}}{1596 \text{ 158.}}Model service life recommended is 3500. hr.; (actual service life 7000 800 hr.;\frac{126}{m} = 32.18 \text{ ft.} 3000 \frac{\text{ft.}^3}{min} \cdot 60 \frac{\text{m}}{\text{ht}}4551 \text{ gm/cc} = 32 (18.6) = \frac{596 \text{ 158.}}{1596 \text{ 158.}}Model service life recommended is 3500. hr.; (actual service life 7000 800 hr.;\frac{126}{min} \cdot 60 \frac{\text{m}}{\text{ht}}Model service life recommended is 3500. hr.; (actual service life 7000 800 hr.;\frac{126}{min} \cdot 60 \frac{\text{m}}{\text{ht}}$	AUTHOR	INGINEEI	DEPARTMENT	UIE	ESO 510	M4906	3 of [
COALESCER: A coalescer stage is needed. The model (Fig. 2) internals are unknown but assumed to be fiberglass. D_{rr} , diameter of model, is 8" Model $V_{g} = \frac{Q}{A} = \frac{60 \text{ SCFM}}{\frac{77}{4} \left(\frac{8}{12}\right)^{2} 17 \text{ atm}} = \frac{3.55 \text{ ACFM}}{.348 \text{ ft.}^{2}} = 10.2 \text{ ft.}/\text{min.}$ Prototype $V_{g} = 10 \text{ ft.}/\text{min.} = \frac{3000}{18 \cdot \text{A}}$; $A = 16.7 \text{ ft.}^{2} = \frac{7}{4} D_{p}^{2}$; $D_{p} = 4.65 \text{ ft.} = 56^{\circ}$ First approximation is a pressure vessel of 56" dia. with stages of fibergla .Other geometries can be used to obtain $A \simeq 16 \text{ ft.}^{2}$ with a smaller, m economical pressure vessel, such as Pall reverse "Utit-Port" miltiple unit $a \le 16 \cdot \text{ cach.}$ (SR UANKLOSA) 'A RAD LLSECK') or BACTON. Concesse CHARCOAL ADSORBER: (Fibure 3) $\nabla^{ast} = \frac{9}{16}$ Model diameter is 6" contact time, $f = \frac{24.65}{18.76 \text{ min.}}$ $\frac{TT}{4} = \frac{60}{12} 17 \text{ atm} = \frac{3.55}{16} = 18.1 \text{ ft.}^{2} \text{ min.}$ Model $V_{g} = \frac{60}{2} 17 \text{ atm} = \frac{3.55}{16} = 18.1 \text{ ft.}^{2} \text{ min.}$ $\frac{TT}{4} = \frac{60}{12} 17 \text{ atm} = \frac{71}{16} \text{ min.}$ Model charcoal bed depth is $\sim 24^{\circ}$; make prototype depth also 24" (2 Prototype $V_{g} = 18.1 = \frac{3000}{A \cdot 18 \text{ atm}}$; $A = 9.26 \text{ ft.}^{2} = \frac{77}{4} D_{p}^{2}$; $D_{p} = 3.28 \text{ ft.} = 39.4^{\circ}$ Model charcoal bed depth is $\sim 24^{\circ}$; make prototype depth also 24" (2 Prototype charcoal volume $V = A^{\beta} = (9.3)(2) = 18.6 \text{ ft.}^{3}$ $\frac{\beta_{act}}{\beta_{act}} \gamma_{act}} \frac{\beta_{act}}{\beta_{act}} \frac{\beta_{act}}{\beta_{act}} \gamma_{act}} \frac{\beta_{act}}{\beta_{act}} \gamma_{act} \frac{\beta_{act}}{\beta_{act}} \gamma_{act}} \gamma_{act}$ Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; flow is $3000 \frac{\text{ft.}^{3}}{\text{min}} + 60 \frac{\text{m}}{\text{hr}}^{2}$ 700 $= 126 \times 10^{7} \text{ ft.}^{3}$ (.011 $\frac{\text{hs}}{\text{ft}^{3}} \oplus 0^{\circ} \text{C}$, 1 atm $= 13 \times 10^{6} \text{ hs}$.	R.	Byrns	Mechanical E	ngineering	Berkeley	18 February	y 1976
A coalescer stage is needed. The model (Fig. 2) internals are unknown but assumed to be fiberglass. $D_{m}, \text{ diameter of model, is 8''}$ $Model V_{s} = \frac{Q}{A} = \frac{60 \text{ SCFM}}{\frac{T}{4} \left(\frac{8}{12}\right)^{2} 17 \text{ atm}} = \frac{3.55 \text{ ACFM}}{.348 \text{ ft.}^{2}} = 10.2 \text{ ft./min.}$ $Prototype V_{s} = 10 \text{ ft./min.} = \frac{3000}{18 \cdot A}; A = 16.7 \text{ ft.}^{2} = \frac{T}{4} D_{p}^{2};$ $D_{p} = 4.65 \text{ ft.} = 56''$ First approximation is a pressure vessel of 56'' dia. with stages of fibergla .Other geometries can be used to obtain $A \simeq 16 \text{ ft.}^{2}$ with a smaller, m economical pressure vessel, such as Pall reverse ''Uti-Por'' multiple unit $\sim 5 \text{ ft.}^{2}$ each. (QR HANKINSON'' APR QLESCER'') car CALSTON. Concepter CHARCOAL ADSORBER. (Figure 3) $\frac{10}{2} \text{ ft.}^{2} = \frac{2 \text{ ft}}{18^{27} \text{ min}}$ is 6.75 ft.^{2} Model diameter is 6'' contact time, $\mathcal{A} = \frac{2 \text{ ft}}{18^{27} \text{ min}}$. $\frac{10000}{m} = 6.75 \text{ ft.}^{2}$ Model V_{s} = \frac{60}{4 \text{ to ft}^{2}} = \frac{3.55}{12} = 18.1 \text{ ft.}^{2}/\text{min}. $\frac{17}{4} - \frac{6}{12} = 17 \text{ atm}} \frac{77}{16}$ Prototype V_{s} = 18.1 = $\frac{3000}{A \cdot 18 \text{ atm}}$; $A = 9.26 \text{ ft.}^{2} = \frac{77}{4} \text{ D}_{p}^{2}$; $D_{p} = 3.28 \text{ ft.} = 39.4''$ Model charcoal bed depth is $\sim 24''$; make prototype depth also 24'' (2 Prototype charcoal volume $V = A A^{\frac{1}{2}} (9.3)(2) = 18.6 \text{ ft.}^{3}$ Charcoal density ($\frac{1}{7} \text{ JXC} - 610.8 \text{ mesh}$); cost $\sim 31.00 \text{ per lb.}$) .4551 gm/cc $\simeq 32 \text{ lb./ft.}^{3}$ Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr.; We with flow of 3000 SCFM for 7000 hr.; $\sum \text{flow is 3000} \frac{\text{ft.}^{3}}{\text{min}} + 60 \frac{\text{m}}{\text{hr}}^{2}$ 70 $= 126 \times 10^{7} \text{ ft.}^{3}$, 001 $\frac{15s}{67} \oplus 0^{\circ}$, 1 atm $\frac{126 \times 10^{6} \text{ ft.}^{3}}{\text{min}} + 60 \frac{\text{m}}{\text{m}}^{2}$ 70	<u>C0</u>	ALESCER:					
$\begin{split} & D_{m}, \text{ diameter of model, is 8''} \\ & \text{Model } V_{s} = \frac{Q}{A} = \frac{60 \text{ SCFM}}{\frac{77}{4} - \left(\frac{8}{12}\right)^{2} 17 \text{ atm}} = \frac{3.55 \text{ ACFM}}{.348 \text{ ft.}^{2}} = 10.2 \text{ ft./min.} \\ & \text{Prototype } V_{s} = 10 \text{ ft./min.} = \frac{3000}{18 \cdot A}; A = 16.7 \text{ ft.}^{2} = \frac{77}{4} D_{p}^{2}; \\ & D_{p} = 4.65 \text{ ft.} = 56'' \\ \end{split} \\ & \text{First approximation is a pressure vessel of 56'' dia. with stages of fibergla . Other geometries can be used to obtain A ~ 16 \text{ ft.}^{2} with a smaller, m economical pressure vessel, such as Pall reverse ''Ulti-Por'' multiple unit ~ 5 \text{ ft.}' each. (QR HANKINGON'' ABBQLESCHE'') OR CALSTON. CALESCE CHARCOAL ADSORBER. (Fibure 3) \nabla^{a_{0}} \nabla^{a_{0}} \mathcal{P} \\ \text{Model diameter is 6'' contact time, ft = } \frac{2ft}{18^{-7} \text{ min.}} \frac{L_{0}66c}{m} = 6.75 \text{ st.} \\ \text{Model V}_{s} = \frac{60}{12} \frac{17 \text{ atm}}{716} \frac{77}{16} \frac{16}{12} \frac{18.6 \text{ ft.}^{2}}{18.6 \text{ ft.}^{2}} \frac{17}{4} \text{ D}_{p}^{2}; \\ D_{p} = 3.28 \text{ ft.} = 39.4'' \\ \text{Model charcoal bed depth is } 24''; make prototype depth also 24'' (2 \text{ Prototype charcoal volume V} = A \mathcal{I} = (9.3)(2) = 18.6 \text{ ft.}^{3} \frac{16}{10} \frac{1000 \text{ pr}}{10} \text{ st.} \frac{15}{100 \text{ pr}} \text{ st.} \frac{1000 \text{ pr}}{16} \frac{1}{10} \frac{1000 \text{ pr}}{10} \frac{1}{10} \frac{1}{10} \frac{1000 \text{ pr}}{10} \frac{1}{10} \frac{1000 \text{ pr}}{10} \frac{1}{10} \frac{1000 \text{ pr}}{10} \frac{1}{10} \frac$	but	A coalescer s assumed to be	tage is needed. fiberglass.	The model (•	Fig. 2) inter	nals are unk	nown
Model $V_s = \frac{Q}{A} = \frac{60 \text{ SCFM}}{\frac{T'}{4} \left(\frac{8}{12}\right)^2 17 \text{ atm}} = \frac{3.55 \text{ ACFM}}{.348 \text{ ft}^2} = 10.2 \text{ ft}./\text{min.}$ Prototype $V_s = 10 \text{ ft}./\text{min.} = \frac{3000}{18 \cdot \text{A}}$; $A = 16.7 \text{ ft}.^2 = \frac{T'}{4} D_p^2$; $D_p = 4.65 \text{ ft}. = 56^{\circ\circ}$ First approximation is a pressure vessel of 56'' dia. with stages of fibergla .Other geometries can be used to obtain $A \simeq 16 \text{ ft}.^2$ with a smaller, m economical pressure vessel, such as Pall reverse ''Ulti-Por'' multiple unit $\approx 5 \text{ ft}.^2$ each. (QR HANKINGON' AERDLESCEE'') or PALSTON. CALESCE CHARCOAL ADSORBER. (Fibure 3) $\sqrt{\alpha c_V} = 9$ Model diameter is 6'' $contact thme_{r} f = \frac{2 \text{ ft}}{18^{-7} \text{ fm}}$. $\frac{Logge}{m} = 6.75 \text{ ft}$ Model $V_s = \frac{60}{2} = \frac{3.55}{12} = 18.1 \text{ ft}.^2/\text{ such}$. $\frac{TT}{4} = \frac{6}{12} 17 \text{ atm} = \frac{T'}{16}$ Prototype $V_s = 18.1 = \frac{3000}{A \cdot 18 \text{ atm}}$; $A = 9.26 \text{ ft}.^2 = \frac{T'}{4} D_p^2$; $D_p = 3.28 \text{ ft}. = 39.4''$ Model charcoal bed depth is $\simeq 24''$; make prototype depth also 24'' (2 Prototype charcoal volume $V = AA = (9, 3)(2) = 18.6 \text{ ft}.^3$ $\frac{Max}{Max} \frac{Max}{Max} \frac{Max}{Max}$ Charcoal density ($\frac{4}{3}$ JXC - 6 to 8 mesh); $\cot x \leq 1.00 \text{ per lb.}$) .4551 gm/cc $\simeq 32$ (18.6) = $\frac{1596 \text{ lbs.}}{1596 \text{ lbs.}}$ Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; flow is $3000 \frac{\text{ft}.^3}{\text{min}} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 700 \frac{100}{100} \frac{110}{100} \frac{100}{100} 10$		D _m , diameter	of model, is 8	311		•	,
Prototype $V_s = 10$ ft. /min. = $\frac{3000}{18 \cdot A}$; A = 16, 7 ft. $^2 = \frac{\pi}{4} D_p^2$; $D_p = 4.65$ ft. = 56" First approximation is a pressure vessel of 56" dia. with stages of fibergla .Other geometries can be used to obtain A $\simeq 16$ ft. 2 with a smaller, m economical pressure vessel, such as Pall reverse "Ulti-Por" multiple unit ≈ 5 ft. 2 each. (of HANKINSON) AFROLESERE") or PALSTON. CONCESSE <u>CHARCOAL ADSORBER</u> . (Fibure 3) γ^{acp-9} Model diameter is 6" contact three, $f = \frac{2 \text{ ft}}{18^{-7}/\text{min}}$. $\frac{6060}{\text{m}} = 6.75\text{ ft}$ Model V _s $\approx \frac{60}{12}$ 17 atm $\frac{\pi}{16}$ Prototype V _s = 18.1 = $\frac{3000}{A \cdot 18 \text{ atm}}$; A = 9.26 ft. $^2 = \frac{\pi}{4}$ D_p^2 ; $D_p = 3.28$ ft. = 39.4" Model charcoal bed depth is $\simeq 24$ "; make prototype depth also 24" (2 Prototype charcoal volume V = $A_{s}^{2} = (9, 3)(2) = 18.6 \text{ ft}$. 3 <i>Example Contact</i> f_{stick} Charcoal density (# JXC - 6 to 8 mesh); cost ~\$1.00 per lb.) .4551 gm/cc $\simeq 32$ lb. /ft. 3 Adsorber charge $\simeq 32$ (18.6) = <u>596 lbs.</u> Model service life recommended is 3500 r. hr.; (actual service life 7000 8000 hr. With flow of 3000 SCFM for 7000 hr.; flow is $3000 \frac{\text{ft}.^3}{\text{min}} + 60 \frac{\text{m}}{\text{hr}} \cdot 700 \frac{100}{100} \frac{100}{1$		Model $V_s = -$	$\frac{Q}{A} = \frac{60 \text{ s}}{\frac{77}{4} \left(\frac{8}{12}\right)}$	CFM = 2 17 atm .	3.55 ACFM 348 ft. ²	= 10.2 ft./r	nin.
First approximation is a pressure vessel of 56" dia. with stages of fibergla ,Other geometries can be used to obtain A ~ 16 ft. ² with a smaller, m conomical pressure vessel, such as Pall reverse "Ulti-Por" multiple unit. ~ 5 ft. ² each. (\Re HANKINKON' A& QLL&EKCL') Ox CALSTON. CALESCE CHARCOAL ADSORBER. (Fibure 3) $\varphi^{ag} \sim 9$ Model diameter is 6" contact time, $f_{c} = \frac{2 ft}{18} \frac{1}{18} \frac{1}{16} \frac{1}{18} \frac{1}{16} $		Prototype V _s	= 10 ft./min. =	$\frac{3000}{18 \cdot A} ; A = D_{p}$	$= 16.7 \text{ ft.}^2 =$ = 4.65 ft. =	$\frac{\mathcal{T}}{4} D_{p}^{2};$	
.Other geometries can be used to obtain A $\simeq 16$ ft. ² with a smaller, m economical pressure vessel, such as Pall reverse "Ulti-Por" multiple unit ~ 5 ft. ² each. (\mathcal{R} HANKINSON, "AEROLLSERE") or BALSTON. concesses CHARCOAL ADSORBER. (Fibure 3) $\overline{\gamma}^{aco} \sim 9$ Model diameter is 6" contact time, $\overline{t} = \frac{2 \text{ ft}}{18 \pi m}$. $\frac{60 \text{ fec}}{m} = 6.75$. Model V _s $= \frac{60}{12}$ $\frac{217}{17}$ atm $\frac{77}{16}$ Prototype V _s = 18.1 = $\frac{3000}{A \cdot 18 \text{ atm}}$; A = 9.26 ft. ² = $\frac{77}{4}$ D ² _p ; D _p = 3.28 ft. = 39.4" Model charcoal bed depth is $\simeq 24$ "; make prototype depth also 24" (2 Prototype charcoal volume V = A = (9.3)(2) = 18.6 ft. ³ $\frac{factor Partial}{factor Partial}$ Charcoal density (# JXC - 6 to 8 mesh); cost \sim \$1.00 per 1b.) .4551 gm/cc $\simeq 32$ (18.6) = $\frac{596 \text{ Ibs}}{1596 \text{ Ibs}}$ Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; flow is 3000 $\frac{\text{ft.}^3}{\text{min}} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 700$ $= 126 \times 10^7 \text{ ft.}^3$ (.011 $\frac{\text{Ibs}}{\text{ft.}^3}$ @ 0°C, 1 atm $=$:13 x 10 ⁶ lbs.	Fir	st approximatio	on is a pressur	e vessel of 56	" dia. with s	tages of fibe	rglass
CHARCOAL ADSORBER. (Figure 3) $\nabla^{aa_{ab}} ?$ Model diameter is 6'' $contact time, \Lambda = \frac{2 ft}{18^{-7/min}} \frac{b 0 kt}{m} = 6.75$. Model $V_s = \frac{60}{12} = 3.55 = 18.1 \text{ ft} \cdot \frac{2}{18^{-7/min}} \frac{10}{m} = \frac{6.75}{m} = \frac{3.55}{16} = 18.1 \text{ ft} \cdot \frac{2}{18} \frac{1000}{m}$. Prototype $V_s = 18.1 = \frac{3000}{A \cdot 18 \text{ atm}}$; $A = 9.26 \text{ ft} \cdot \frac{2}{4} = \frac{77}{4} D_p^2$; $D_p = 3.28 \text{ ft} = 39.4^{''}$ Model charcoal bed depth is $224^{''}$; make prototype depth also 24'' (2 Prototype charcoal volume $V = A \lambda^2 = (9.3)(2) = 18.6 \text{ ft} \cdot \frac{3}{16}$ Charcoal density (# JXC - 6 to 8 mesh); cost \sim \$1.00 per lb.) .4551 gm/cc $232 \text{ lb} \cdot /\text{ft} \cdot \frac{3}{16}$ Model service life recommended is 3500 fr.; (actual service life 7000 8000 hr.) With flow of 3000 SCFM for 7000 hr.; $\sum_{n=10}^{10} flow$ is $3000 \frac{\text{ft} \cdot \frac{3}{min} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 700 \text{ hr}$. $= 126 \times 10^7 \text{ ft} \cdot \frac{3}{4} \cdot 0111 \frac{\text{lbs}}{\text{ft}^3} \oplus 0^{\circ}\text{C}$, 1 atm $23 \times 10^6 \text{ lbs}$.	есо ~5	Other geometr nomical pressu ft. ² each. (98	ries can be use tre vessel, suc HANKINSON'	d to obtain A h as Pall reve AEROLESCER	$\sim 16 \text{ ft.}^2 \text{ w}$ rse "Ulti-Po") oz BALS	ith a smalles r'' multiple	r, mor units c SCER
Model diameter is 6'' contact time, $X = \frac{18}{18}$ mm m c of rest Model V _s = $\frac{60}{\frac{7T}{4} - \frac{6}{12}} = \frac{3.55}{17 \text{ atm}} = 18.1 \text{ ft} \cdot \frac{2}{17}$ min. *. $\frac{7T}{4} - \frac{6}{12} = 17 \text{ atm}}{16} = \frac{7T}{16}$ Prototype V _s = 18.1 = $\frac{3000}{A \cdot 18 \text{ atm}}$; A = 9.26 ft. $^2 = \frac{7T}{4} D_p^2$; D _p = 3.28 ft. = 39.4'' Model charcoal bed depth is ~ 24 ''; make prototype depth also 24'' (2 Prototype charcoal volume V = $A_x^2 = (9.3)(2) = 18.6 \text{ ft} \cdot \frac{3}{16}$ Charcoal density (# JXC - 6 to 8 mesh); cost \sim \$1.00 per lb.) .4551 gm/cc ~ 32 lb./ft. 3 Adsorber charge ~ 32 (18.6) = $\frac{596 \text{ lbs.}}{1596 \text{ lbs.}}$ Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr. With flow of 3000 SCFM for 7000 hr.; \sum_{r} flow is $3000 \frac{\text{ft.}}{16} \cdot \frac{3}{16} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 70$ = 126 x 10 ⁷ ft. $\frac{3}{2}$ (.0111 $\frac{\text{lbs}}{\text{ft}^3} \oplus 0^{\circ}$ C, 1 atm $\sum_{r=13}^{r} x 10^6 \text{ lbs.}$	CHA	ARCOAL ADSO	RBER. (Figur	e 3) yang 9	: 2ft	60500 6	7000
Model V _s = $\frac{60}{\frac{\pi}{4}} = \frac{3.55}{62} = 18.1 \text{ ft} \cdot \frac{2}{3} / \frac{\pi}{4}$ ⁴ . $\frac{\pi}{4} = \frac{6}{12} = 17 \text{ atm} = \frac{\pi}{16}$ Prototype V _s = 18.1 = $\frac{3000}{A \cdot 18 \text{ atm}}$; A = 9.26 ft. ² = $\frac{\pi}{4} = D_p^2$; D _p = 3.28 ft. = 39.4" Model charcoal bed depth is ~ 24 "; make prototype depth also 24" (2 Prototype charcoal volume V = A = (9.3)(2) = 18.6 ft. ³ Charcoal density (# JXC - 6 to 8 mesh); cost ~\$1.00 per lb.) .4551 gm/cc ~ 32 lb./ft. ³ Adsorber charge ~ 32 (18.6) = <u>596 lbs.</u> Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; \sum flow is 3000 $\frac{\text{ft}}{3} + 60 \frac{\text{m}}{\text{hr}} \cdot 700$ $= 126 \times 10^7 \text{ ft} \cdot \frac{3}{4} \cdot 0111 \frac{\text{lbs}}{\text{ft}^3} @ 0^{\circ}\text{C}$, 1 atm $\sum = 13 \times 10^6 \text{ lbs}$.		Model diamete	eris 6" Co.	ntact time, j	L = 18 1/min	m	f f and 5,,5 ₀₀ ρ
Prototype $V_s = 18.1 = \frac{3000}{A \cdot 18 \text{ atm}}$; $A = 9.26 \text{ ft.}^2 = \frac{\pi}{4} D_p^2$; $D_p = 3.28 \text{ ft.} = 39.4^{"}$ Model charcoal bed depth is $24^{"}$; make prototype depth also 24" (2 Prototype charcoal volume $V = A_s^2 = (9,3)(2) = 18.6 \text{ ft.}^3$ Charcoal density (# JXC - 6 to 8 mesh); cost \sim \$1.00 per lb.) .4551 gm/cc 232 lb./ft.^3 Adsorber charge 232 lb./ft.^3 Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; $\sum_{r=10}^{100} 1000 \frac{\text{ft.}^3}{\text{min}} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 7000$ $= 126 \times 10^7 \text{ ft.}^3 (.0111 \frac{\text{lbs}}{\text{ft}^3} @ 0^\circ\text{C}, 1 \text{ atm}) = 13 \times 10^6 \text{ lbs.}$		Model V ===================================	$ \frac{60}{77} \frac{2}{6} \frac{1}{12} $	= 3.55 = .7 atm $\frac{77}{16}$	18.1 ft. ² /see	ćn.	
Model charcoal bed depth is $24''$; make prototype depth also 24'' (2 Prototype charcoal volume V = A_{e}^{A} = (9.3)(2) = 18.6 ft. ³ Charcoal density (# JXC - 6 to 8 mesh); cost ~\$1.00 per lb.) .4551 gm/cc 232 lb./ft. ³ Adsorber charge 232 (18.6) = 596 lbs. Model service life recommended is 3500 fr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; flow is 3000 $\frac{\text{ft.}^{3}}{\text{min}} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 700$ = 126 x 10 ⁷ ft. ³ (.0111 $\frac{\text{lbs}}{\text{ft}^{3}}$ @ 0°C, 1 atm = 13 x 10 ⁶ lbs.		Prototype V _s	$= 18.1 = A \cdot 18$	$\frac{3000}{3 \text{ atm}}$; A = 9	$.26 \text{ ft.}^2 = \frac{7}{4}$	$\sum_{p} D_{p}^{2};$	
Model charcoal bed depth is $\sim 24^{11}$; make prototype depth also 24 ¹¹ (2 Prototype charcoal volume V = A $A = (9, 3)(2) = 18.6$ ft. ³ Charcoal density (# JXC - 6 to 8 mesh); cost ~\$1.00 per lb.) .4551 gm/cc ~ 32 lb./ft. ³ Adsorber charge ~ 32 (18.6) = <u>596 lbs.</u> Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr. With flow of 3000 SCFM for 7000 hr.; $\sum_{i=126 \times 10^7 \text{ ft.}}^3 (0.0111 \frac{\text{lbs}}{\text{ft}^3} = 0.0^{\circ}\text{C}, 1 \text{ atm} = 13 \times 10^6 \text{ lbs}.$				D _p -	J.20 II J9	• 4	
Prototype charcoal volume V = A_{μ}^{μ} = (9.3)(2) = 18.6 ft. Charcoal density (# JXC - 6 to 8 mesh); cost ~\$1.00 per lb.) .4551 gm/cc ~ 32 lb./ft. ³ Adsorber charge ~ 32 (18.6) = <u>596 lbs.</u> Model service life recommended is 3500 hr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; $\sum_{n=1}^{\infty}$ flow is 3000 $\frac{\text{ft.}^3}{\text{min}} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 700$ = 126 x 10 ⁷ ft. ³ (.0111 $\frac{\text{lbs}}{\text{ft}^3}$ @ 0°C, 1 atm = 13 x 10 ⁶ lbs.		Model charcoa	il bed depth is	\sim 24"; make	e prototype d	epth also 24	'' (2 ±t
Charcoal density (# JXC - 6 to 8 mesh); $\cot x$ \$1.00 per lb.) .4551 gm/cc \simeq 32 lb./ft. ³ Adsorber charge \simeq 32 (18.6) = 596 lbs. Model service life recommended is 3500. hr.; (actual service life 7000 8000 hr.; With flow of 3000 SCFM for 7000 hr.; \sum flow is 3000 $\frac{\text{ft.}^3}{\text{min}} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 700$ = 126 x 10 ⁷ ft. ³ (.0111 $\frac{\text{lbs}}{\text{ft}^3}$ @ 0°C, 1 atm $=$ 13 x 10 ⁶ lbs.		Prototype cha	rcoal volume V	$= A_{\chi} = (9.3)(2)$:) = 18.6 ft.		
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Model service life recommended is 3500 hr.; (actual service life 7000 8000 hr.) With flow of 3000 SCFM for 7000 hr.; $\sum_{n=1}^{\infty} flow is 3000 \frac{ft.^3}{min} \cdot 60 \frac{m}{hr} \cdot 700$ = 126 x 10 ⁷ ft. $\frac{3}{1000}$. 0111 $\frac{1bs}{ft^3}$ @ 0°C, 1 atm = 13 x 10 ⁶ lbs.		Adsorber chan	$ge \sim 32 (18.6)$	= <u>596 lbs</u> .			·
With flow of 3000 SCFM for 7000 hr.; $\sum_{r=10}^{r}$ flow is $3000 \frac{\text{ft.}^3}{\text{min}} \cdot 60 \frac{\text{m}}{\text{hr}} \cdot 700$ = 126 x 10 ⁷ ft. $\frac{3}{1000}$. 0111 $\frac{1\text{bs}}{\text{ft}^3}$ @ 0°C, 1 atm = 13 x 10 ⁶ 1bs.		Model service	life recommen	nded is 3500. 1	hr.; (actual s	service life	7000 -
= 126×10^7 ft. ³ /. 0111 $\frac{1bs}{ft^3}$ @ 0°C, 1 atm = 13 x 10 ⁶ lbs.		He. With flow of 3	000 SCFM for ⁻	7000 hr.;∑flo	w is 3000 <u>ft.</u>	$\frac{3}{1} \cdot 60 \frac{m}{hr}$	7000
		= 12	$6 \times 10^7 \text{ ft.} \frac{3}{.000}$	$\lim \frac{1 \text{bs}}{\text{ft}^3} @ 0^{\circ}\text{C}$	1 atm = 1	3 x 10 ⁶ 1bs.	

RT - 3990 - 20 (Rov 8/71)

R. ByrnsMachanical EngineeringBarkeleyBrekeleyIf oil impurity is 1 ppm by weight, we need to adsorb 13 lbs of oilIf oil is 1 ppm by volume, He volume is $\frac{126 \times 10^7}{18 \text{ atm}} = 7 \times 10^7 \text{ Sft.}^3$ We need to adsorb 70 ft. ³ of oil vapor.If oil vapor density is 0.2 - 0.4 lb. /ft. ³ , we need to absorb 14-2If charcoal absorbs 10-15% of its weight in oil vapor before breakthen 600 lbs. of charcoal sorbs 60-90 lbs. of oil and we have adequatfactor.PRESSURE DROP THRU CHARCOAL. \triangle P = DL (K ₁ / μ V + K ₂ ρ V ²) see page SD = bed density (30 lbs. /ft. ³)K ₁ = 7.05L = bed depth (2 ft.) μ = viscosity, 200 x 10 ⁻⁶ pose = .02 centipose ρ = density at 18 atm \pm 0.198 lbs. /ft. ³ V _s = superficial velocity (100 fpm) = 0.18 ft. /min. Δ P = 30 (2) $\boxed{7.05}$ (.02) (0.18) + 2.12 (0.198) (.0325) $\boxed{7}$ = 60 $\boxed{.0254}$ z 60 (0.162) = \triangle P = 9.72 inches of H ₂ OMAXIMUM ALLOWABLE VELOCITY (to prevent bed destruction)G ² = .0167 dd Dg d_a = bed density, 30. lbs. /ft. ³ d_a = bed density, d_a (b) (.010) (32.2) = 0.032 = 3.2 x 10^{-7} d_a = bed density, d_a (b) (.010) (32.2) = 0.032 = 3.2 x 10^{-7}	4 OF
If oil impurity is 1 ppm by weight, we need to adsorb 13 lbs of oil If oil is 1 ppm by volume, He volume is $\frac{126 \times 10^7}{18 \text{ atm}} = 7 \times 10^7 \text{ Sft.}^3$ We need to adsorb 70 ft. ³ of oil vapor. If oil vapor density is 0.2 - 0.4 lb./ft. ³ , we need to absorb 14-2 If charcoal absorbs 10-15% of its weight in oil vapor before break then 600 lbs. of charcoal sorbs 60-90 lbs. of oil and we have adequat factor. <u>PRESSURE DROP THRU CHARCOAL</u> . $\angle P = DL (K_1 \mu V + K_2 \rho V^2) \dots$ see page 5 $D = \text{bed density (30 lbs./ft.}^3)$ $K_1 : 7.05$ $L = \text{bed depth (2 ft.)}$ $K_2 = 2.12$ $\mu = \text{viscosity, 200 x 10^{-6}}$ pose = .02 centipose $\rho = \text{density at 18 atm : 0.198 lbs./ft.}^3$ $V_s = \text{superficial velocity (100 fpm)} = 0.18 \text{ ft./min.}$ $\Delta P = 30 (2) \int 7.05 (.02) (0.18) + 2.12 (0.198) (.0325) \int = 60 \int .0254$ z = 60 (0.162) = $\Delta P = 9.72 \text{ inches of H}_2O$ <u>MAXIMUM ALLOWABLE VELOCITY</u> (to prevent bed destruction) $G^2 = .0167 \text{ d} Dg$ $3c_{C} \rho \approx e^{4/5}$ $d_g = \text{gas density; 0.198 lbs./ft.}^3$ $D = \text{av. particle}$ $d_a = \text{bed density, 30. lbs./ft.}^3$ $D = \text{av. particle}$ $G^2 = (0.0167) (0.198) (30) (.010) (32.2) = 0.032 = 3.2 \times 10^{-7}$ $G_{\text{max}} = 1.79 \times 10^{-1} = 0.179 \text{ lbs./sec. ft.}^2$	y 18, 1976
If oil is 1 ppm by volume, He volume is $\frac{126 \times 10^7}{18 \text{ atm}} = 7 \times 10^7 \text{ Sft.}^3$ We need to adsorb 70 ft. ³ of oil vapor. If oil vapor density is 0.2 - 0.4 lb./ft. ³ , we need to absorb 14-2 If charcoal absorbs 10-15% of its weight in oil vapor before break then 600 lbs. of charcoal sorbs 60-90 lbs. of oil and we have adequat factor. <u>PRESSURE DROP THRU CHARCOAL</u> . \bigtriangleup P = DL (K ₁ μ V + K ₂ ρ V ²) see page 5 D = bed density (30 lbs./ft. ³) K ₁ = 7.05 L = bed depth (2 ft.) K ₂ = 2.12 μ = viscosity, 200 x 10 ⁻⁶ pose = .02 centipose ρ = density at 18 atm = 0.198 lbs./ft. ³ V _s = superficial velocity (100 fpm) = 0.18 ft./min. $A P = 30 (2) \int 7.05 (.02) (0.18) + 2.12 (0.198) (.0325) \int = 60 \int .0254$ = 60 (0.162) = $\boxed{A P = 9.72}$ inches of H ₂ O <u>MAXIMUM ALLOWABLE VELOCITY</u> to prevent bed destruction) G ² = .0167 d d Dg $\frac{346}{2} \frac{346}{2} \frac{5}{2}$ d _g = gas density; 0.198 lbs./ft. ³ D = av. particle $\frac{G^2}{ga} = (0.0167) (0.198) (30) (.010) (32.2) = 0.032 = 3.2 x 10^{-1}$ G _{max} = 1.79 x 10 ⁻¹ = <u>0.179 lbs./sec.ft.²</u>	
We need to adsorb 70 ft. ³ of oil vapor. If oil vapor density is 0.2 - 0.4 lb. /ft. ³ , we need to absorb 14-2 If charcoal absorbs 10-15% of its weight in oil vapor before break then 600 lbs. of charcoal sorbs 60-90 lbs. of oil and we have adequat factor. PRESSURE DROP THRU CHARCOAL. $\triangle P = DL (K_1 / \mu V + K_2 / 2 V^2) \dots$ see page 5 $D = bed density (30 lbs. /ft. ^3)$ $K_1 = 7.05$ $L = bed depth (2 ft.)$ $K_2 = 2.12$ $\mu = viscosity, 200 \times 10^{-6}$ pose = .02 centipose $P = density at 18 atm = 0.198 lbs. /ft. ^3$ $V_s = superficial velocity (100 fpm) = 0.18 ft. /min.$ $\Delta P = 30 (2) \int 7.05 (.02) (0.18) + 2.12 (0.198) (.0325) = 60 \int .0254$ = 60 (0.162) = $\Delta P = 9.72$ inches of H ₂ O MAXIMUM ALLOWABLE VELOCITY (to prevent bed destruction) $G^2 = .0167 d d Dg$ $Acc parts^{4-5}$ $d_g = gas density; 0.198 lbs. /ft. ^3$ $D = av. particle g = 32.2 ft. /secG^2 = (0.0167) (0.198) (30) (.010) (32.2) = 0.032 = 3.2 \times 10^{-1}G_{max} = 1.79 \times 10^{-1} = 0.179 lbs. /sec. ft. ^2$	
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If charcoal absorbs 10-15% of its weight in oil vapor before break then 600 lbs. of charcoal sorbs 60-90 lbs. of oil and we have adequat factor. <u>PRESSURE DROP THRU CHARCOAL</u> . $\triangle P = DL (K_1 \mu V + K_2 \rho V^2) \dots$ see page 5 $D = \text{bed density (30 lbs./ft.}^3)$ $K_1 = 7.05$ $L = \text{bed depth (2 ft.)}$ $K_2 = 2.12$ $\mu = \text{viscosity, 200 x 10^{-6}}$ pose = .02 centipose $\rho = \text{density at 18 atm} = 0.198 \text{ lbs./ft.}^3$ $V_s = \text{superficial velocity (100 fpm)} = 0.18 \text{ ft./min.}$ $\Delta P = 30 (2) \boxed{7.05 (.02) (0.18) + 2.12 (0.198) (.0325)} = 60 \boxed{.0254}$ = 60 (0.162) = $\Delta P = 9.72 \text{ inches of H}_2O$ <u>MAXIMUM ALLOWABLE VELOCITY</u> (to prevent bed destruction) $G^2 = .0167 \text{ dd Dg}$ $\exists L c \neq a \neq 5^{-5}$ $d_g = \text{gas density; 0.198 lbs./ft.}^3$ $D = \text{av. particle}$ $d_a = \text{bed density, 30. lbs./ft.}^3$ $d_a = \text{bed density, 30. lbs./ft.}^3$ $G^2 = (0.0167) (0.198) (30) (.010) (32.2) = 0.032 = 3.2 \times 10^{-5}$ $G_{\text{max}} = 1.79 \times 10^{-1} = 0.179 \text{ lbs./sec. ft.}^2$	lbs oil.
PRESSURE DROP THRU CHARCOAL. $\triangle P = DL (K_1 \mu V + K_2 \rho V^2) \dots \text{ see page 5}$ $D = \text{ bed density (30 lbs./ft.}^3) \qquad K_1 = 7.05$ $L = \text{ bed depth (2 ft.)} \qquad K_2 = 2.12$ $\mu = \text{ viscosity, 200 x 10^{-6} pose = .02 centipose}$ $P = \text{ density at 18 atm : z 0.198 lbs./ft.}^3$ $V_s = \text{ superficial velocity (100 fpm) = 0.18 ft./min.}$ $\triangle P = 30 (2) [7.05 (.02) (0.18) + 2.12 (0.198) (.0325)] = 60 [.0254]$ $= 60 (0.162) =$ $\triangle P = 9.72 \text{ inches of H}_2O$ $MAXIMUM ALLOWABLE VELOCITY (to prevent bed destruction)$ $G^2 = .0167 d d Dg \qquad J(c) \rho e^{c} \delta^{-5}$ $d_g = \text{ gas density; 0.198 lbs./ft.}^3 \qquad D = \text{ av. particle}$ $d_a = \text{ bed density, 30. lbs./ft.}^3 \qquad D = \text{ av. particle}$ $G^2 = (0.0167) (0.198) (30) (.010) (32.2) = 0.032 = 3.2 \times 10^{-5}$ $G_{max} = 1.79 \times 10^{-1} = 0.179 \text{ lbs./sec.ft.}^2$	-through, e safety
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RL-3220-2a(Rev.8/71)

R. Byrns ED. NOTE

ESO 510

M4906 Supplement to Catalog Section S-6450 Data Sheet No. 1



(1 Atm. pressure and 70°F)

GENERAL EQUATION FOR PRESSURE DROP FOR ANY FLUID THRU A PACKED GRANULAR BED:

$$\frac{\mathbf{P}}{\mathbf{DL}} = \mathbf{K}_{1} \boldsymbol{\mu} \mathbf{V} + \mathbf{K}_{2} \boldsymbol{\rho} \mathbf{V}^{2}$$

- P = Pressure drop (inches water)
- $D = Bed density (lbs /ft ^3)$
- μ = Fluid viscosity (centipose)
- ρ = Fluid density (lbs /ft ³)
- V = Superficial fluid velocity (100 fpm) L = Bed depth (ft)

Reference: Fluid Flow Through Packed Columns Chem. Eng. Progress Vol. 48; No.

2, Pg. 89, February, 1952

"Columbia" is

1.055	0.282
3.33	1.33
7.05	2.12
2.8	4.04
15.8	4.12
	1.055 3.33 7.05 2.8 5.8

*Based on P for air at 1 atm. and 70°F. MAXIMUM ALLOWABLE GAS VELOCITY TO PREVENT DESTRUCTION OF ACTIVATED CARBON BED:

$$\frac{G^2}{d_g d_a D g} = 0.0167$$

- G = Maximum mass velocity (lbs /sec ft²)
- $d_g = Density of gas (lbs /ft ³)$
- $d_a = Density$, packed bed (lbs /ft ³)
- D = Average particle diameter (ft)
- g = Gravitational constant (32.2 ft/sec ²)

Reference: Avoiding Destructive Velocity through Adsorbent Beds. Ledoux Chem. Eng. March, 1948.

Telephone Contacts

Chicago, III. (312) 822-7000 • Los Angeles, Calif. (213) 583-3061 • New York, N.Y. (212) 551-2345 Pittsburgh, Pa. (412) 922-5700 • San Francisco, Calif. (415) 765-1000

UNION CARBIDE CORPORATION CARBON PRODUCTS DIVISION 270 'PARK AVENUE, NEW YORK, N.Y. 10017 Export: International Department, New York In Canada: Union Carbide Canada Limited, Toronto

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Form CP-3147 Rev. 1 1.5M 5-73

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CODE SERIAL PAGE LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA ESO 510 NOTE M4906 ENGINEERING of [] AUTHOR LOCATION DATE DEPARTMENT Meets 24 Feb76 Burns OTES ON CHARCOAL FROM WESTVACO CHEM. DIV. NUCHAR" CATALOG. COVINGTON, VA. 24426

Because of its incredibly porous structure, activated carbon has a singular ability to adsorb materials from gases and liquids. Each particle holds a vast interconnecting network of many-sized pores. This provides a very large surface area for adsorption of molecules. '

Almost always, adsorption on activated carbon is the result of so called "van der Waals," or "dispersion," forces. This is physical adsorption. These forces exist among all molecules or atoms, whether or not they are chemically combined. The same forces are primarily responsible for the condensation or liquefaction of vapors. The forces of attraction which a particle of activated carbon exerts upon molecules in its vicinity may be compared to the gravitational forces the earth exerts upon objects near it. As a rule, molecules with a higher molecular weight experience greater forces of attraction than materials of lower molecular weight. Hence, activated carbons, aside from the effects of molecular screening due to the sizes of the pores, have a preference for higher molecular weight substances.

A particle of activated carbon has associated with it an "atmosphere" of adsorbed molecules in much the same way the earth has a surrounding atmosphere of air. A granule of activated carbon placed in contact with a mixture of gases of various molecular weights will adsorb a mixture of all the gases present. It will adsorb a greater proportion of the higher molecular weight gases, however.

When a granule of activated carbon is placed in contact with a liquid mixture, there is a similar tendency for higher molecular weight substances to be adsorbed. In liquid systems, however, activated carbon tends to "prefer" not only substances of higher molecular weight but also non-polar substances. Thus, there is an affinity for the adsorption of non-polar organic molecules from polar solvents such as water. *Figure 2* represents an enlarged portion of the pore structure showing absorbed molecules (the spheres) within the pores of the carbon particle.

The forces of attraction between the carbon and adsorbate molecules increase directly as the size of the adsorbate molecules approaches the size of the pores. The most tenacious adsorption takes place when the pores are barely large enough to admit the adsorbate molecules. To put it another way: the nearer the pore size to the diameter of the molecules, the greater the attraction. The pores cannot be so small that the adsorbate molecules cannot enter, or else the adsorptive capacity for those molecules will be greatly reduced. Since adsorbate molecules are physically prohibited from entering pores smaller than those molecules, the size distribution of pores is a critical factor in adsorption. A carbon with pores predominately smaller than the desired adsorbate will have a low capacity for that particular adsorbate. Consequently, the pore structure of activated carbons is extremely important in determining their adsorptive properties.

Although the reasons are not completely understood, it is known that the presence of other elements can have a considerable influence on adsorptive properties of carbon. Particularly important is oxygen, which can exist in a variety of chemically combined forms with the atoms on the particle surfaces. These oxygen groups appear to increase the adsorptivity of the carbon for polar compounds. In some circumstances the inorganic "ash" portion of an activated carbon can also be important in determining adsorptive properties.

FIG. 1 BELOW IS FROM "LINDE" MOL.SIEVE CATALOG.







- 120 ^{Nm³} /hr. (GOSCETIN) HERMETIC TWO-S		E SCREN	M.TNO - MARTINA MAGO	THIS PAGE AND NEXT DESCRIBE OL REMOVAL SYSTEM FOR A 2-STAGE HERMETIC SCREW COMPRESSOR MYLON FROM A PAPER AT CRYD. ENGR CONFKINGSTON-ONT JUNE 1975 CONFKINGSTON-ONT JUNE 1975 NEW TYPE SCREW COMP. FOR HELIVM REFARGE LIQUEFIERS	RIBYRNS ENGANOTE ESO510
Measuring Sampling Location	Pres	sure atm	Pressure Drop (Pc–Ps) atm	Oil Content CH ₄ Equivalent(ppm)	Mły
Compressor Outlet	Pc	17.0			906
No.1 Oil Separator Outlet	Ps	16.9	0.1	140	
No.40il Separator Outlet	Ps	15.9	1.1	0.1	
No.5 Oil Separator Outlet	Ps	15.6	1.4	0.04	pag

(DP 150 HIGH)

OIL CONTENT ANALYSIS BY GAS CHROMATOGRAPHY RESULTS REPRESENTED BY METHANE EQUIVALENT OIL USED." SUNISO" - (MINERAL) REFRIG, GRADE

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