Project Name	**Skykomish**
Project/Task Number	**1140204/0360**
Calculation Title	**Air Sparging System Blower Sizing**
Prepared by	**D. Arcieri**
Reviewed by	**M. Havighorst**
Completion date	**11/4/2007**

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Objective: To determine minimum blower operating pressure for Area 1 injection wells and future potential injection wells (aka Area 2 Well) based on system head losses and subsurface conditions.

Step 1. Determine Pressure Drop in Straight Runs of Pipe due to friction, h_f

PIPING RUN	FROM	TO	PIPE DIA (in)	PIPE DIA D (ft)	PIPE LENGTH L (ft)	DESIGN FLOW[b] Q (SCFM)	DESIGN FLOW[1] Q (ACFM)	DESIGN VEL.[2] v (fps)	TEMP (deg F)	Re[3] (dim)	RELATIVE ROUGHNESS[4] ε/D	FRICTION FACTOR[5] f (ft)	HEAD LOSS[6] h_f (ft)	PRESSURE DROP[7] p_{f1} (lbf/ft^2)	PRESSURE DROP[8] p_{f2} (psi)
Area 1															
	Mech. Bldg.	Vault 1	4	0.33	550	51	66	13	80	24921	1.50E-05	2.45E-02	100	8	0.05
	Vault 1	Area 1 Wells	1	0.08	140 [a]	3	4	12	80	5864	6.00E-05	3.62E-02	133	10	0.07
Total													234	18	0.12
Area 2 [b]															
	Mech. Bldg.	Vault 2	4	0.33	730	24	31	6	80	11727	1.50E-05	2.97E-02	36	3	0.02
	Vault 2	Area 2 Wells	1	0.08	180 [c]	3	4	12	80	5864	6.00E-05	3.62E-02	172	13	0.09
Total													207	16	0.11

Notes:

a Pipe length is to the Area 1 sparging well furthest from Vault 1. Length is based on 2008 EDR drawing C-17 takeoff.

b The locations of the Area 2 vault and sparging wells have not been determined, but would likely be located north of Area 1 and near the South Fork Skykomish River. Area 2 wells and piping would be constructed similarly to those installed in Area 1.

c Pipe length was estimated based on the predicted location of the future potential Area 2 sparging well furthest from the likely future potential location of Vault 2.

Calculations

1. $Q_{ACFM} = Q_{SCFM}\,[P_{std} / (P_{act} - P_{sat}\Phi)](T_{act} / T_{std})$ **where**

ACFM = Actual Cubic Feet per Minute
SCFM = Standard Cubic Feet per Minute
Pstd = Standard absolute air pressure (psia)
Pact = absolute pressure at the actual level (psia)
Psat = Saturation pressure at the actual temperature (psi)
Φ = Actual relative humidity
Tact = Actual ambient air temperature (R)
Tstd = Standard temperature (R)

Assumptions:
1. Pact = 13.66 psi at site elevation of 2000 ft above mean sea level
2. Φ = 0.70
3. Tact = 80^{o}F, 540R

2. $v = Q(\pi D^2/4)/(60\ \text{sec/min})$

3. $Re = Dv/\nu$ **where**

ν = kinematic viscosity(lbf-sec/ft^2)

Assumptions:

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1. ν = 0.000169 lbf-sec/ft^2 at 80^{o}F

4. ε = 0.000005 ft where
ε = roughness factor for plastic pipe (Lindeburg, Table 17.2, p. 17-4)

5. $$f = \frac{0.25}{\left[\log_{10}\left(\frac{\frac{\varepsilon}{D}}{3.7}\right) + \frac{5.74}{\text{Re}^{0.9}}\right]^2}$$ (Lindeburg, Eq. 17.21)

6. $h_f = fLv^2/(2Dg)$ (Lindeburg Eq. 17.28) where
g = acceleration of gravity, 32.2 ft/sec^2

7. $p_{f1} = h_f \rho g_{air}$ (Lindeburg, Eq. 17.29(a)) where
ρg_{air} = specific weight of air at STP, 0.0752 lbf/ft^3

8. $p_{f2} = p_f(144\ in^2/ft^2)$

Step 2. Determine Pressure Drop in Fittings, h_m

Fitting Type	K	No. of Fittings	HEAD LOSS[9] h_m (ft)	PRESSURE DROP[7] p_{m1} (lbf/ft^2)	PRESSURE DROP[8] p_{m2} (psi)
Area 1					
Mechanical Building					
gate valve (4-inch)	0.19	1	0.47	0.04	0.0002
check valve (4-inch)	2.3	1	5.70	0.43	0.0030
90 elbow (4-inch)	0.9	2	4.46	0.34	0.0023
flow meter	5	1	12.39	0.93	0.0065
Vault A					
gate valve (4-inch)	0.19	1	0.47	0.04	0.0002
tee (4-inch), stem flow	1.8	1	4.46	0.34	0.0023
gate valve (1-inch) 1/2 closed	5.6	1	12.30	0.92	0.0064
tee (1-inch), stem flow	1.8	1	3.95	0.30	0.0021
flow meter	5	1	10.98	0.83	0.0057
Area A Wellheads					
90 elbow (1-inch)	0.9	1	1.98	0.15	0.0010
Total			**57.17**	**4.30**	**0.03**

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Area 2					
Mechanical Building					
gate valve (4-inch)	0.19	1	0.47	0.04	0.0002
check valve (4-inch)	2.3	1	5.70	0.43	0.0030
90 elbow (4-inch)	0.9	2	4.46	0.34	0.0023
flow meter	5	1	12.39	0.93	0.0065
Vault B					
gate valve (4-inch)	0.19	1	0.10	0.01	0.0001
tee (4-inch), stem flow	1.8	1	0.99	0.07	0.0005
gate valve (1-inch) 1/2 closed	5.6	1	12.30	0.92	0.0064
tee (1-inch), stem flow	1.8	1	3.95	0.30	0.0021
flow meter	5	1	10.98	0.83	0.0057
Area B Wellheads					
90 elbow (1-inch)	0.9	1	1.98	0.15	0.0010
Total			**53.32**	**4.01**	**0.03**

Calculations

9. $h_m = Kv^2/2g$ (White, Eq. 6.109)

Step 3. Determine Air Entry Pressure, p_e

Assume air entry pressure due to screen friction is 1 psi

p_e = 1psi

Step 4. Determine Total Head Losses Area 1 and 2 Wellheads located furthest from the blower system

$P_{TOTAL} = p_{f2} + p_{m2} + p_e$

Area 1	p_{TOTAL} = 0.12 psi + 0.03 psi + 1 psi =	**1.15 psi**
Area 2	p_{TOTAL} = 0.11 psi + 0.03 psi + 1 psi =	**1.14 psi**

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Step 5. Determine Overburden Pressure, p_o

Calculations

10. $p_o = p_h + p_s$ where **(USACE, Eq. 5-3)**

p_h = hydrostatic pressure from the water column = $\rho g_{water}(z_s - z_w)\phi$ (USACE, Eq. 5-2)

p_s = soil column pressure = $\rho g_{soil} z_s (1-\phi)$ (USACE, Eq. 5-1)

ρg_{water} = specific weight of water at STP, 62.4 lbf/ft^3

ρg_{soil} = specific weight of soil (lbf/ft$^{3)}$

z_s = depth to the top of the well screen (ft)

z_w = depth to high ground water table (ft)

ϕ = porosity

Assumptions:

1. ρg_{soil} = 100 lbf/ft^3
2. ϕ = .5

From Data:

1. z_s = 24 ft
2. z_w = 10 ft

p_o = 62.4 lbf/ft^3(24ft - 10ft)(0.5)+100 lbf/ft^3 (10ft)(0.5) =	937	lbf/ft^2
p_o = 937 lbf/ft^2 (144 in^2/ft^2) =	**6.1 psi**	

Step 6. Determine Range of Maximum Injection Pressure at Well, p_{max}

Calculations

11. $p_{max} = p_o$ (0.6 to 0.8) (USACE, Eq. 5-4)

p_{max} = 6.1 (0.6 to 0.8) = 3.7 to 4.9 psi

Step 7. Determine Minimum Blower Pressure, p_{BLOWER}, Based on Total Pressure Loss and Range of Maximum Injection Pressures

Calculations

12. $p_{BLOWER} > p_{max} + p_{TOTAL}$

Area 1	p_{BLOWER} > 4.9 psi+ 1.15 psi >	**6.05 psi**
Area 2	p_{BLOWER} > 4.9 psi+ 1.14 psi >	**6.04 psi**

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Conclusion: the minimum blower operating pressure is approximately 6.1 psi for each sparging area.

References

1. Lindeburg, Michael R., *Civil Engineering Reference Manual*, 8th Edition, 2001
2. White, F.M., *Fluid Mechanics*, 2nd Edition, 1986
3. United States Army Corps of Engineers (USACE) Engineering Manual (EM) 1110-1-4005 (1997)