MNO2 Abatement - 36" Accumulator Table CFM Rating

Note Title 8/2/2008

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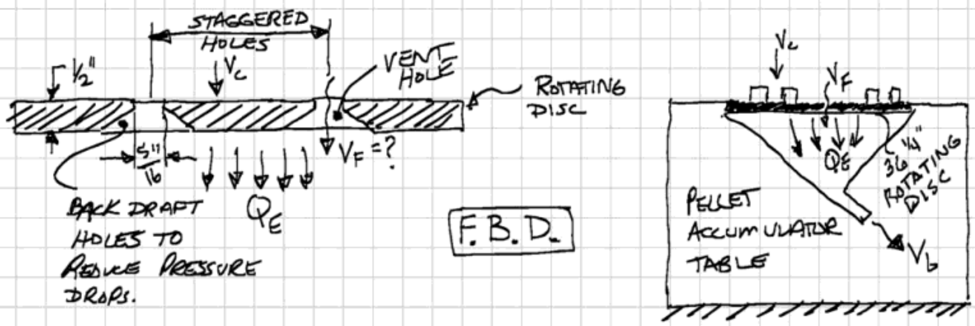
Problem:

Design an exhaust system for the pellet accumulator table by using a downdraft exhaust hood with the rotating dial made with 5/16" diameter perforated holes. The pellet accumulator table has (3) rotating dials: (1) 36.25"dia. and (2) 10" dials. Design the system for constant "exhaust" volumetric flow rate. Size the exhaust outlet for a 6" duct port in order to maintain a steady state flow. NOTE: 100fpm or greater is generally used for capturing particulates. Design the plenum so that it maintains a transport velocity of 4,500 fpm throughout the plenum.

Assumptions:
- Smooth holes
- Minimum cross-draft
- Isothermal & Adiabatic
- Perforated disc acts as a flanged open hood with correct hole spacings
- Constant cross-sectional area of plenum to maintain transport velocities of 4,500 fpm
- Transport velocity of 4,500 fpm

KNOWNS:

$$\rho_{granulated} = 27.5\ g/m^3 \quad (104.3\ lb/ft^3)$$



GENERAL NOTES

— WE KNOW THAT WE WANT A TRANSPORT VELOCITY OF APPROXIMATELY 4,500 FPM. OSHA STATES FOR HEAVY OR MOIST DUST THE TRANSPORT VELOCITY MUST BE GREATER THAN 4,500 FPM. FOR COARSE DUST, OSHA STATES A 4,000 ~ 4,500 FPM RANGE. THESE CALCULATIONS WILL BE BASED UPON A TRANSPORT VELOCITY OF 4,500 FPM.

SOLUTION

I. SINCE WE KNOW OUR TARGET "TRANSPORT" VELOCITY OF 4,500 FPM AND WE WILL CHOOSE A 6" DUCT SINCE IT'S EASIER TO DOWN SIZE VS. UPSIZE, LETS CALCULATE THE EXHAUST FLOW RATE, Q_E, FOR THE SYSTEM!

$6"\phi = 1/2$ FT.

$$Q_E = 4{,}500\ FPM \left(\frac{\pi (1/2)^2}{4}\right) \Rightarrow \boxed{Q_E = 883.6\ scfm}$$

$$(EQ\text{-}1) \rightarrow Q_E = V_{duct}(A_{duct})$$

(This is the system's EXHAUST RATING THAT WE HAVE CHOSEN TO USE

II. THE ANALYSIS OF THIS PROBLEM CAN BE QUITE SIMPLIFIED BY TREATING EACH VENT HOLE AS A FLANGED PLAIN OPENED HOOD. NOW THAT WE KNOW OUR SYSTEM'S EXHAUST RATE, LETS CALCULATE OUR VENT HOLE VELOCITY BY USING A 5/16"Ø HOLE (THIS WAS CHOSEN BASED UPON A 3D SOLID MODELING LAYOUT).

REFENCE P/N 1401-02-011

(A.) THE SOLID MODEL GIVES US A TOTAL OF 1,920 (5/16"Ø) HOLES. NOW WE CAN CALCULATE THE VENT HOLE FLOW RATE,

(EQ.-2b)

$$\dot{m}_v = Q_v(\rho_{granulated})$$

(1.) $$Q_v = \frac{Q_E}{\text{\# OF VENT HOLES}}$$ (EQ-2a) ← IMPORTANT EQ.

$$Q_v = \frac{883.6\ cfm}{1{,}920\ \text{HOLES}}$$

$$Q_v = 0.46\ SCFM/\text{HOLE}$$

(2.) $$\dot{m}_v = \frac{ft^3}{min}\left(\frac{lb}{ft^3}\right)$$

$$\dot{m}_v = 0.46\frac{ft^3}{min}\left(104.8\frac{lb}{ft^3}\right)$$

$$\boxed{\dot{m}_v = 48.21\frac{lbs}{min}/\text{HOLE}}$$

$\dot{m}_v$ = mass flow rate per vent

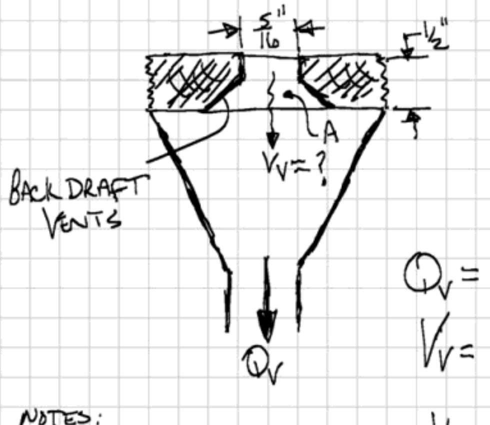
Q_v = VOLUMETRIC FLOW PER VENT

Q_E = EXHAUST VOLUMETRIC FLOW

(3) $$\dot{m}_v = 48.21\frac{lbs}{min}/\text{HOLES}(1{,}920\ \text{HOLES}) = \boxed{92{,}559.4\ \frac{lbs}{MIN.}}$$

TOTAL AMOUNT OF MNO2 THAT CAN BE REMOVED FROM THE TABLE PER MIN.

(B.) NOW, LETS FIND THE VELOCITY THROUGH OUR VENT HOLES,



$$A_v = \frac{\pi D^2}{4} = \frac{\pi(.026FT)^2}{4} = \boxed{5.309\times10^{-4}\ FT^2}$$

VENT HOLES → 5/16"Ø → 0.0260 FT

0.07669 in²

$$Q_v = V_v A_v \quad (EQ-3)$$

$$V_v = \frac{Q_v}{A_v}$$

Q_v = VOLUMETRIC FLOW RATE PER VENT

V_v = Velocity Thru (1) VENT HOLE

A_v = VENT OPENING SURFACE AREA

$$V_v = \frac{0.46\ scfm}{5.309\times10^{-4}\ FT^2}$$

$$\boxed{V_v = 866.8\ \frac{FT}{MIN}}$$

VELOCITY OF AIR THRU (1) VENT HOLE

NOTES:

GENERALLY YOUR AREA AT THE FACE HOOD MUST EQUAL TO OR BE GREATER THAN THE AREA OF YOUR EXHAUST IN ORDER TO BE ABLE TO PULL ENOUGH CFM.

NOTE: ANSI RECOMMENDS 80 ~ 125 fpm OF FACE VELOCITIES. WE ARE 8 TIMES THAT. HOWEVER, IT IS EASIER TO THROTTLE BACK BY USING A DAMPER OR DOWNSIZE THE DUCT VERSUS INCREASING THE DUCT Ø.

III Since the hood design is to be a down draft design, the particulates is said to be at the face of the accumulator table disc ∴ the captured velocity will later be calculated. As stated within the "Industrial Ventilation: A Manual of Recommended Practice for Design" (IVM), flanges allow the face of the hood can reduce the required flow rate by 25% to achieve the same velocity.

∴ "We treat each vent hole as a flanged hood"

The perforated plate is to have no larger than $\frac{5}{16}$" Ø holes due to possible pellet feeding issues on the table. The $\frac{5}{16}$" Ø holes are to be spaced by using the following equation:

$$HS \geq \sqrt{A_H} \quad \text{(EQ-4)}$$

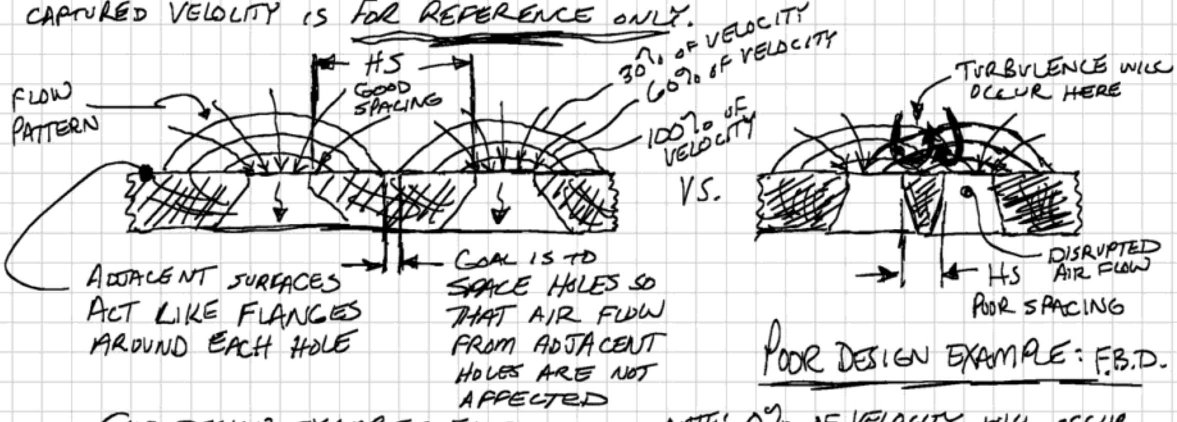
A_H = Hood opening area (Remember from above we're treating each hole as if they are individual hoods in order to keep pulling air in from adjacent holes (balance flow thru the holes for steady flow conditions).

HS = Vent hole spacing

$$HS \geq \sqrt{5.309 \times 10^{-4}\ Ft^2} = 0.02304\ Ft = \boxed{0.2764\text{" spacing between holes}}$$

Note:
The hole spacing is critical ~ too much spacing will leave particulates on the table and too little spacing will dead head flow by producing inadequate flow thru the holes.

IV Now that we have determined the hood flow rate per hole, lets now calculate the captured velocity. Typically, you usually size the hood flow rate by calculating the captured velocity then the face velocity. However, downdraft hoods assume that the particulates will fall down into the hood since the face of the hood is located at the source (pellets). We are only intested in knowing what the captured velocity is for reference only.



Poor Design Example: F.B.D.

Good Design Example: F.B.D.

Note! 0% of velocity will occur at X = hole diameter

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$$Q_V = V_c(10x^2 + A) \quad \text{(EQ-5)}$$

V_c = CAPTURED VELOCITY = ? AT X=0.2" → WHAT IS INDUSTRY RECOMMENDED FOR THIS TYPE OF PARTICULATES
AT X=0.5"

$A_V = 5.309 \times 10^{-4}\ FT^2$

$Q_V = 0.46$ CFM

$10(.2)^2_{.0167ft} =$

$10x^2 = .002778$

AT $X = 0.2"$ ~ WE WANT TO KNOW AT WHAT DISTANCE
$X = 0.5"$

AT $X = 0.0167$ FT,
$(10x^2 + A) = 0.0033198\ FT^2$

AT $X = 0.2"$ (0.0167FT),

AT $X = 0.04167$ FT,
$(10x^2 + A) = 0.01789\ FT^2$

$$\frac{Q_V}{(10x^2 + A)} = V_c$$

$$V_c = \frac{0.46\ scfm}{0.0033198\ FT^2} = \boxed{138.6\ FPM} \text{ AT } X = 0.2"$$

$$V_c = \frac{0.46}{0.01789\ FT^2} = \boxed{25.1\ FPM} \text{ AT } X = 0.5"$$

V. AS WE PREVIOUSLY DISCUSSED, THE HOOD DUCT PORT OUTLET SHALL BE RATED FOR A 6"Ø DUCT. THIS CAN LATER CHANGED TO A SMALLER SIZE OR THROTTLED USING A DAMPER. NOW LETS FIND THE AVG. VELOCITY PRESSURE, VP_d, BY USING BERNOULLI'S EQUATION:

$$\text{(EQ-6)} \quad VP_d = \left(\frac{V_{duct}}{4005}\right)^2 = \left(\frac{4500}{4005}\right)^2 = \boxed{1.27"\ w.g.}$$

~ DUCT VELOCITY PRESSURE IN WATER GAUGE OR COLUMN IN THE HOOD.

VI. NOW LETS FIND THE HOOD ENTRY LOSS AND HOOD STATIC PRESSURE:

(A) $$h_h = F_h(VP_d) \quad \text{(EQ-7)}$$

F_h = FRICTION FACTOR AND CAN BE FOUND IN THE IVM

h_s is negligible since face velocities < 1,000 fpm ∴ was not used in calculations

$$h_h = 0.49(1.27"\ w.g.)$$

HOOD ENTRY = VENT HOLE = h_h

$$\therefore \boxed{h_e = 0.622"\ w.g.}$$

PRESSURE DROP AT HOOD ENTRY (VENT) IN WATER GAUGE OR COLUMN

(B) $$SP_h = -(1 + F_h)(VP_d) \quad \text{(EQ-8)}$$

also known as the hood static suction pressure

$F_d = 0.49$ FOR FLANGED OPENINGS (SEE IVM)

$$= -(1 + 0.49)(1.27"\ w.g.)$$

h_h = Hood Entry loss

$$\therefore \boxed{SP_h = -1.892"\ w.g.}$$

STATIC PRESSURE IN THE HOOD (VENT) IN WATER GAUGE OR COLUMN

$$\boxed{T_P = -1.892 + 1.27 = -0.622"\ w.g.}$$

T_P = TOTAL PRESSURE LOSS IN HOOD

"VENT HOLE LOSSES"

VII. NOW, LETS FIND OUT IF OUR FLOW IS LAMINAR OR TURBULENT THRU THE VENT HOLES

(A) REYNOLDS NUMBER IS GIVEN BY: PER VENT HOLE

$$R_e = \frac{D_v \cdot V_v}{\nu} \quad \text{(EQ-9)}$$

ν = KINEMATIC VISCOSITY OF AIR AT ATM & 70°F = $1.58 \times 10^{-4}\ \frac{ft^2}{s}$

$R_e > 4000 \rightarrow$ TURBULENT

$R_e < 2000 \rightarrow$ LAMINAR

D_v = VENT HOLE Ø = 0.02604 FT

V_v = VENT HOLE VELOCITY $= 866.8\ \frac{FT}{MIN}\left(\frac{1\ MIN}{60\ SEC}\right) = 14.445\ FT/SEC$

$$R_e = \frac{(0.02604\,FT)\left(14.445\,\frac{FT}{SEC}\right)}{1.64 \times 10^{-4}\ FT^2/SEC}$$

$\therefore$ $R_e = 2{,}294$

LAMINAL FLOW ~ CLOSE TO 2,000

(B) FROM THE MOODY DIAGRAM, $f \approx 0.027$

$$\text{(EQ-10)} \quad \frac{f L_v}{D_v} = \frac{(0.027)(0.00258\,FT)}{0.026\,FT} = 0.00268$$

L_v = Length of Vent hole, 0.0026'

D_v = Ø OF VENT hole, 0.026'

f = 0.027 – friction factor

$V = 14.445\ \frac{ft}{sec} \Rightarrow 866.8$ FPM

$\therefore$

(C) Head loss is,

h_{f_v} = VENT HOLE THRU VENT

$$\text{(EQ-11)} \quad h_{f_v} = f\left(\frac{L_v V^2}{D\,2g}\right) = 0.027\left(\frac{0.0026\,ft\,(14.445\,ft/sec)^2}{0.026\,ft\,(2)(32.2\,ft/s^2)}\right)$$

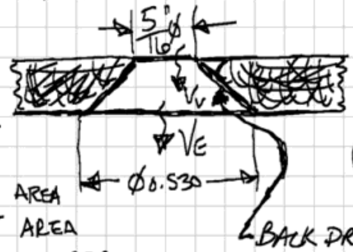
(.5425)

$$= 0.027\left(\frac{0.5425}{1.6744}\right)$$

$\therefore$

Head loss thru Vent hole $\longrightarrow$ $h_{f_v} = 0.0087$ ft (0.105 INCHES) Thru the Vent hole

VIII. SINCE WE KNOW THE FACE VELOCITY AT THE 5/16"Ø VENT HOLE, WE CAN FIND THE VELOCITY AT THE EXIT END OF THE VENT HOLE (0.513"Ø) BY



USING CONSERVATION OF MASS

$$\text{(EQ-12)} \quad V_v A_v = V_E A_E$$

$$(5.309 \times 10^{-4}\,ft^2)\left(866.8\,\frac{Ft}{MIN}\right) = V_E\,(0.0015321\,FT^2)$$

V_v = VENT HOLE FACE VELOCITY

A_v = VENT HOLE FACE AREA

V_E = VENT HOLE EXIT AREA

A_E = VENT HOLE EXIT AREA

$V_v = 866.8$ FT/MIN

$A_v = 5.309 \times 10^{-4}\ ft^2$

$A_E = \frac{\pi (.044167\,FT)^2}{4}$

$A_E = 0.0015321\ FT^2$

$\therefore$ $V_E = 300.4$ FT/MIN

AT EXIT END OF VENT HOLE PRIOR TO ENTERING THE 4,500 fpm Transport stream

IX. THE EFFECT OF A BACK DRAFT:

AS DEMONSTRATED ABOVE BY CALCULATING THE VENT HOOD EXIT VELOCITY, THE PRESSURE DROP IS REDUCED BY FINDING THE % REDUCTION IN VELOCITY SINCE PRESSURE IS A FUNTION OF VELOCITY IN PIPING.

$$\frac{866.8 - 300.4}{866.8} \times 100\% =$$ **65% REDUCTION IN BOTH VELOCITY AND PRESSURE DROP**

X. PLENUM DESIGN

PLENUMS MUST BE DESIGNED CAREFULLY IN ORDER TO PULL THE PROPER Velocities FROM THE SYSTEM. THE "IDEAL" PLENUM WOULD BE WHEN THE CROSS-SECTIONAL AREA IS "CONSTANT" AND MATCHES THE CROSS-SECTIONAL AREA OF THE EXHAUST PORT (DUCT SIZE). IF THIS IS OBTAINED THEN THE VELOCITY IN THE PLENUM WILL EQUAL TO THE VELOCITY IN THE EXHAUST DUCT BY THE LAW OF CONSERVATION OF MASS.

LAW OF CONSERVATION OF MASS STATES:

$$A_P V_P = A_D V_D \quad \text{(EQ-13)}$$

- A_P = Plenum Area X-SECTION
- V_P = Plenum Velocity
- EXHAUST:
  - A_D = DUCT Area X-SECTION
  - V_D = DUCT velocity (transport)

IF $A_P = A_D$ THEN EQ-13 BECOMES:

$$V_P = \frac{A_D V_D}{A_P}$$

$$\therefore \quad V_P = V_D$$

AREA OF EXHAUST DUCT
6"Ø DUCT

$$A_D = \frac{\pi D^2}{4} = \pi\frac{(6)^2}{4}$$

$$A_D = 28.27 \text{ in}^2$$

THIS TELLS US THAT THE MOST EFFICIENT PLENUM DESIGN WILL ALWAYS BE THAT WHERE THE X-SECTIONAL AREAS, AT ANY GIVEN POINT, WITHIN THE PLENUM MATCHES THE X-SECTIONAL AREA OF THE EXHAUST DUCT (TRANSPORT).

∴ THE PLENUM X-SECTIONAL AREA MUST EQUAL:

$$A_P = A_D = 28.27 \text{ in}^2$$