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Paper machine vacuum selection factors

Scope

The purpose of this Technical Information Paper is to provide a *reference basis* from which paper machine vacuum system airflow requirements may be calculated. Air flow sizing requirements for fourdriniers, press sections, tissue formers and cylinder machines are presented.

Selection factors given in this TIP are only guidelines. Vacuum system suppliers, machine builders, or application specialists should be consulted for accurate sizing and for specific applications.

Safety precautions

Mill safety requirements and other precautions should be taken when working with vacuum pumps and other paper machine equipment. Be careful of intakes for vacuum system inbleed valves.

General comments

Standard vacuum system sizing factors can only be applied to conventional paper machine geometries using typical operating practices. Vacuum sizing factors are used to simplify the vacuum sizing process.

All vacuum levels shown are measured at the paper machine service not at the vacuum pumps.

Conversion factors

<u>multiply</u>	<u>by</u>	<u>to obtain</u>	<u>multiply</u>	<u>by</u>	<u>to obtain</u>
lb	0.454	kg	ft/min (fpm)	0.305	m/min (mpm)
oz	28.35	g	ft ³ /min	1.669	m ³ /hr
oz/ft ²	305.6	g/m ² (gsm)	ft ³ /min /in.	0.669	m ³ /hr/cm
in.	25.4	mm	ft ³ /min /in. ²	0.263	m ³ /hr/cm ²
in.	2.54	cm	ft ³ /min /in. ² /1000ft ³ /min	0.0863	m ³ /hr/cm ² /100mpm
in.	0.0254	m			
in. Hg	13.6	in H ₂ O	psi	27.77	in. H ₂ O
in. Hg	1.13	ft H ₂ O	psi	2.315	ft H ₂ O
in. Hg	0.489	psi	psi	6.895	kPa
in. Hg	3.386	kPa			
kPa	0.295	in. Hg			

TIP Category: Automatically Periodically Reviewed (Five-year review)



Documents

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Influence of temperatures and altitude

I. Temperatures

Airflow carried from the paper machine into the vacuum system consists of air and water vapor. If the vacuum system is composed of liquid ring pumps, temperature differences between the water vapor in the air stream and the seal water used for the vacuum pumps should be taken into consideration for pump sizings..

If vacuum pump seal water is cooler than incoming vapor, the vapor will be condensed. The degree of condensation depends on pump design and seal water piping configuration. The volume of dry air that the pump will handle increases in proportion to the volume of vapor that is condensed prior to the vacuum pump.

This condensing affect of liquid ring vacuum pumps increases the air handling capability of the vacuum system by 5 – 20%. The amount of increase depends on the differential between the seal water and process temperatures. It also depends on the operating vacuum level. When selecting a vacuum system to match the airflow requirements determined by the selection factors in this TIP, consult vacuum system suppliers for recommendations on the influence of temperatures on the system selected.

II. Altitude

Barometric pressure decreases as elevation above sea level increases. This reduction in barometric pressure reduces vacuum gauge readings on paper machines.

The selection factors in this TIP can be used for system sizing at any elevation. However, vacuum gauge readings (and power requirements of the vacuum pump) will be lower at elevations above sea level. Influence on vacuum levels and power requirements is negligible for elevations below 3000 ft, and can be ignored. Vacuum system suppliers should be consulted concerning the influence of elevation on system selection.

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Suction roll vacuum box open area

In this TIP, vacuum selection factors for suction rolls are based on suction box open areas measured as shown in ILLUSTRATION 1:

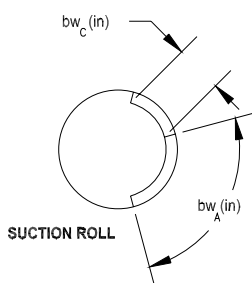


Figure 1.

1. For Suction Box MD Widths ≤ 6 in., use chord length of suction box at Inside Diameter of suction roll shell (bw_C).
2. For Suction Box MD Widths > 6 in. (and ALL tissue machine suction rolls), use arc length of suction box extended to Outside Diameter of roll (including cover) (bw_A).

Paper and board grades

The following comments, descriptions and formulae refer to the forming and press sections on machines producing paper and board grades.

Forming section

It is important to understand that vacuum system requirements for any forming section are developed through calculations which take into account key sizing parameters. The following descriptions apply to forming section vacuum units located in the Appendix -- Figures A1, A2, and A3.

<u>Unit Location</u>	<u>Description</u>
1	vacuum assisted pulsative foil suction boxes
2	low vacuum area of foil suction boxes
3	medium vacuum area of foil suction boxes
4	"wet boxes" - low vacuum area of flat suction boxes
5	"dry boxes" - high vacuum area of flat suction boxes
6	low vacuum area of couch roll
7	high vacuum area of couch roll

Particular attention should be paid to: 1) specific configuration of the forming section; 2) desired vacuum levels; 3) open area in high vacuum drainage elements; and 4) location of dry/wet line; 5) furnish and grade; 6) refining; 7) forming fabric caliper, style and permeability. All of these factors can suggest an increased air flow demand, especially on lightweight grades. A thorough system analysis should also ensure that proper piping layout, separators, and pump sizing are addressed.

The rate at which air is drawn through various grades of paper illustrates that sheet weight, furnish type, freeness and sheet moisture (or consistency) affect results. The amount of air drawn through a sheet is inversely related to its moisture content. No air is drawn through the sheet prior to the dry line. Airflow increases as the sheet is successively dried beyond the dry line.

For a given grade and furnish, airflow is inversely related to sheet weight. This is clearly illustrated on the broad weight ranges of linerboard and bleached paperboard. On traditional lightweight grades the relationship of airflow to sheet weight is not so apparent.

Stock freeness variation is also significant. Large differences between (high freeness) 42-lb linerboard and (low freeness) 30-lb newsprint is evident in the sizing factors. Although there is a 4:1 basis weight ratio between the two grades, similar airflows are required due to the offsetting freeness values.

The largest air flow requirements occur after the dry line on lightweight, free-draining paper grades. Velocity of the air produces drainage as it strips water from the capillaries of the sheet. However, the actual amount of water removed is very small. Thus, in a "dry" position, a suction box cover having a small open area and lower total air flow can achieve the same dewatering as a cover with greater open area, and can reduce energy requirements.

This same drainage mechanism occurs at the couch. Hence, the use of two suction zones operating at successively higher vacuum. Note that the last flatbox prior to a couch may be operating at higher vacuum than the 1st (low vacuum) zone of a two-zone couch.

Figures A1-A3 reflect current industry averages for the applications shown. All references to airflow are in ACFM (actual ft³/min) at the recommended vacuum level. They represent the current norm for the vacuum capacity of modern paper machines in each grade category. Some existing machines may be operating satisfactorily at lower levels. Excess vacuum capacity at the flatboxes, for example, may offset low vacuum capacity at the couch, or vice versa. Also, impact of top wire dewatering equipment can greatly influence (often reduce) flatbox requirements.

However, the values in Figures A1-A3 should be considered if a production upgrade is contemplated. In such instances, careful attention must also be given to pressure drop, sizing of vacuum piping and valves, pre-separators, seal legs, suction roll journal open area, etc., to ensure that the pressure drop between the vacuum source and the point of application does not exceed 1 in. Hg vacuum.

Figures A1-A3 reference two different factors for high vacuum flatbox capacity - one based on a $\text{ft}^3/\text{min}/\text{in.}$ of wire width, and the other based on a $\text{ft}^3/\text{min}/\text{in.}^2$ of open area. The first provides a quick total capacity requirement based upon modern machine speeds and tonnage. The latter should be used for more accurate calculations of needed airflow, and reflects vacuum density needed to develop a desired vacuum level. The implication for mill engineering is that production changes demand evaluation of total ft^3/min needs as well as the suction area through which it will be applied. It also is important that a study of paper machine drive loads and installed drives be undertaken any time additional vacuum capacity is considered.

A general equation for calculating required airflow of a vacuum element is noted below, along with nomenclature and units of measurement:

$$\text{Equation 1: } Q = ww \times V_f \times \#u \times sw \times \#b$$

Where:

Q	total air flow (ACFM @ in. Hg vacuum)
ww	wire width (inches)
V _f	vacuum factor (ACFM/in. ² or ACFM/in.)
#u	number of slots/box
sw	slot width (inches)
#b	number of boxes
md	machine direction length (inches)
cd	cross machine direction (inches)
#u	number of slots/box

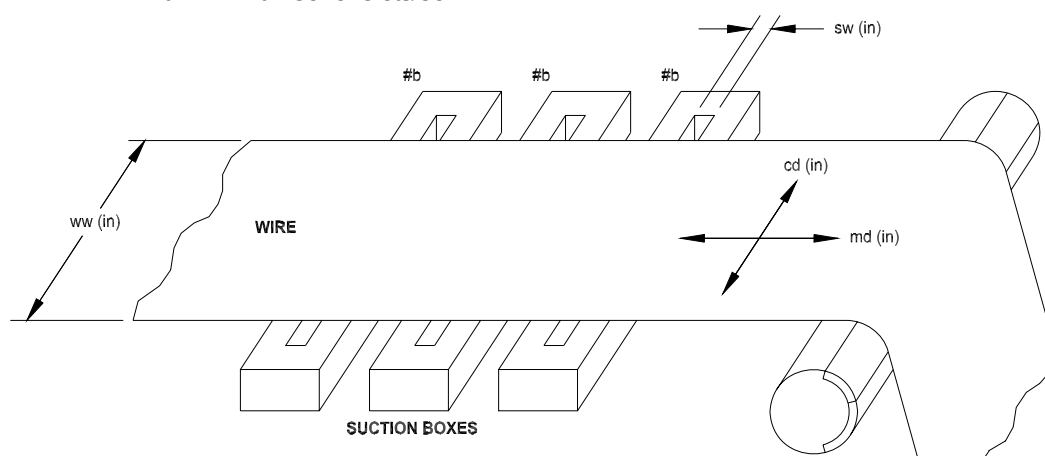


Figure 2.

Note: The vacuum service location numbers in the following examples refer to Figures A1-A3.

Low vacuum foil & suction box requirements

Airflow and differential pressure requirements for the units in locations #1 and #2 are very low as no air is actually being drawn through the sheet. For units in location #3, higher vacuum levels are generally applied as these units operate near the "dry" line and some airflow is starting to occur. Only slotted cover designs are utilized on these

units. To determine airflow requirements for units in these locations, multiply wire (fabric) width $\times$ vacuum factor ($\text{ft}^3/\text{min}/\text{in.}$) $\times$ number of units = total flow required per location.

Example 1A

Calculate requirements for a 240-in. corrugating medium machine operating at a maximum speed of 2000 ft/min with four units in location #1, two units in location #2, and one unit in location #3.

$$\begin{aligned}\text{Location 1: } Q &= ww \times V_f \times \#b = \text{ft}^3/\text{min} @ 38 \text{ in. H}_2\text{O} \\ Q &= 240 \text{ in.} \times 1.5 \text{ ft}^3/\text{min}/\text{in.} \times 4 \text{ units} = 1440 \text{ ft}^3/\text{min} @ 38 \text{ in. H}_2\text{O}\end{aligned}$$

$$\begin{aligned}\text{Location 2: } Q &= ww \times V_f \times \#b = \text{ft}^3/\text{min} @ 38 \text{ in. H}_2\text{O} \\ Q &= 240 \text{ in.} \times 1.5 \text{ ft}^3/\text{min}/\text{in.} \times 2 \text{ units} = 720 \text{ ft}^3/\text{min} @ 38 \text{ in. H}_2\text{O}\end{aligned}$$

$$\begin{aligned}\text{Location 3: } Q &= ww \times V_f \times \#b = \text{ft}^3/\text{min} @ 54 \text{ in. H}_2\text{O} \\ Q &= 240 \text{ in.} \times 3.5 \text{ ft}^3/\text{min}/\text{in.} \times 1 \text{ unit} = 840 \text{ ft}^3/\text{min} @ 54 \text{ in. H}_2\text{O}\end{aligned}$$

The equations above give required airflows at respective vacuum levels. However, since one vacuum source is often used for servicing all three locations, required airflows will have to be expanded to the highest required operating vacuum level (Location 3 vacuum level in this example). This is done by expanding airflow (volume) at the lower vacuum levels to the equivalent airflow (volume) at the highest vacuum level. Boyle's gas law ($P_1V_1 = P_2V_2$), with vacuum levels (P) converted to absolute pressures is used to determine the total expanded airflow requirement.

For Example 1A:

Convert operating vacuum levels to absolute pressure –

(atmospheric pressure = 0 in. H₂O vacuum = 408 in. H₂O absolute pressure)

Location 1: $P_1 = 38 \text{ in. H}_2\text{O vacuum} = 408 \text{ in. H}_2\text{O absolute} - 38 \text{ in. H}_2\text{O} = 370 \text{ in. H}_2\text{O absolute}$
 Location 2: $P_1 = 38 \text{ in. H}_2\text{O vacuum} = 408 \text{ in. H}_2\text{O absolute} - 38 \text{ in. H}_2\text{O} = 370 \text{ in. H}_2\text{O absolute}$
 Location 3: $P_2 = 54 \text{ in. H}_2\text{O vacuum} = 408 \text{ in. H}_2\text{O absolute} - 54 \text{ in. H}_2\text{O} = 354 \text{ in. H}_2\text{O absolute}$

Calculate the airflow requirement (V_1) at Locations 1 & 2 expanded to the highest vacuum level (P_2) -

$$P_1V_1 = P_2V_2$$

$$\therefore V_2 = V_1 \times (P_1 \div P_2)$$

$$\begin{aligned}\text{Location 1: } V_2 &= 1440 \text{ ft}^3/\text{min} \times \frac{370}{354} = 1505 \text{ ft}^3/\text{min} @ 54 \text{ in. H}_2\text{O} \\ \text{Location 2: } V_2 &= 720 \text{ ft}^3/\text{min} \times \frac{370}{354} = 753 \text{ ft}^3/\text{min} @ 54 \text{ in. H}_2\text{O} \\ \text{Location 3: } V_2 &= (\text{no conversion required}) \quad 840 \text{ ft}^3/\text{min} @ 54 \text{ in. H}_2\text{O} \\ &\quad 3098 \text{ ft}^3/\text{min} @ 54 \text{ in. H}_2\text{O}\end{aligned}$$

Therefore, the vacuum source for this example should be capable of providing approximately 3,100 ft^3/min @ 54 in. H₂O vacuum.

High vacuum suction box requirements

Airflow requirements are much greater in locations #4 and #5 - the traditional "wet" and "dry" suction box or flatbox region.

Slotted suction box covers are more widely used in these locations. Their requirements may be calculated in a similar way: multiply [wire (fabric) width] × [number of slots per box × slot width (MD)] × [vacuum factor (ft³/min/in.²)] × [number of boxes]:

$$Q = ww \times \#u \times sw \times V_f \times \#b$$

For suction boxes with "drilled" covers, multiply [wire (fabric) width] × [overall cover width (MD)] × [percent open area of the cover's drilled pattern] × [vacuum factor (ft³/min/in.²)] × [number of boxes]:

$$Q = ww \times bw \times \% OA \times V_f \times \#b$$

Example 1B

Using the corrugating medium machine with four "wet" suction boxes and four "dry" suction boxes, the airflow requirements for locations #4 and #5 are:

Location 4: Slotted Covers: eight 0.75 in. wide slots, 4 boxes

$$Q = ww \times \#u \times sw \times V_f \times \#b = \text{ft}^3/\text{min} @ 10 \text{ in. HgV}$$

$$Q = 240 \text{ in. wire} \times 8 \text{ slots} \times 0.75 \text{ in./slot} \times 0.6 \text{ ft}^3/\text{min} / \text{in.}^2 \times 4 \text{ boxes} = 3456 \text{ ft}^3/\text{min} @ 10 \text{ in. HgV}$$

Location 5: Slotted Covers: six 0.625 in. slots, 4 boxes

$$Q = ww \times bw \times \% \text{ open area} \times V_f \times \#b = \text{ft}^3/\text{min} @ 15 \text{ in. HgV}$$

$$Q = 240 \text{ in. wire} \times 6 \text{ slots} \times 0.625 \text{ in./slot} \times 1.2 \text{ ft}^3/\text{min} / \text{in.}^2 \times 4 \text{ boxes} = 4320 \text{ ft}^3/\text{min} @ 15 \text{ in. HgV}$$

Should these airflows be combined, then 3564 ft³/min @ 10 in. HgV must be expanded to 15 in. HgV for proper sizing of the vacuum source (see Example #1A).

For comparison, a calculation using ft³/min /in. of wire width is shown below.

Based upon the ft³/min /in. guidelines, vacuum specifications for this example would be:

$$\text{Location \#4: } 240 \text{ in.} \times 16 \text{ ft}^3/\text{min}/\text{in.} = 3840 \text{ ft}^3/\text{min} @ 10 \text{ in. Hg}$$

$$\text{Location \#5: } 240 \text{ in.} \times 24 \text{ ft}^3/\text{min}/\text{in.} = 5760 \text{ ft}^3/\text{min} @ 15 \text{ in. Hg}$$

It is important to understand that vacuum capacity and the number of flatboxes both increase in proportion to design production rate.

Suction couch requirements

Actual couch box widths are determined in relation to roll size and wrap angle for a particular machine. The ft³/min/in.² values listed for locations #6 and #7 indicate current industry averages used on couch rolls. It should be noted that this ft³/min/in.² is applied to total couch suction box open area. This active suction area is determined by multiplying the MD length of the suction box (bw) by the width of the forming fabric (ww). **Couch roll shell % open area is not used in determining the required airflow.**

Example 1C

Continuing the corrugating medium example for a 42 in. O.D. couch roll with a single 45° suction box, the required airflow is: