PSIG XXXX

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ABSTRACT

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1 INTRODUCTION AND BACKGROUND

This is the PSIG LaTeX template!

Below we have used a mix of Lorem Ipsum gibberish text for filler along with some excerpts from a book to show how the template can be used to publish your papers!

2 APPROACH

Some filler text to show how these look next to each other. A little bit more here and we have it.

Theorem 1. This is your awesome theorem.

Proof: This is your awesome proof. □

And this leads to the following result that does not even require proof,

Corollary 1. This is your corollary.

And Theorem 1 is illustrated in Figure 1 while Corollary 1 is self-explanatory. We can also peek ahead at the results in Table 2.

3 ANALYSIS

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3.1 The Subsection

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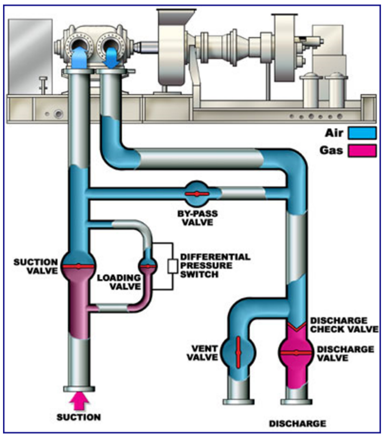

Figure 1 Sample figure.

Table 1 Table of Constant Values

Measurement	Symbol	Unit	Value
Pressure	P	Pa	101325
Temperature	T	K	288
Universal Gas Constant	R	$\frac{N\cdot m}{mol\cdot K}$	8.314
Number of Moles	N	None	1
Volume	V	m^3	0.0235

Table 2 Example table of results

Column heading	Column heading two	Column heading three
Row 1a	Row 1b	Row 1c
Row 2a	Row 2b	Row 2c
Row 3a	Row 3b	Row 3c
Row 4a	Row 4b	Row 4c
Row 5a	Row 5b	Row 5c
Row 6a	Row 6b	Row 6c

- list item 1
- list item 2
- etc.

And The Subsubsection without numbers

Here is a subsubsection with an ordered bullet list:

1. list item 1
2. list item 2
3. etc.

4 RESULTS

The general pipe flow equation is given in [1, Chapter 2] as equation (2.2), shown below:

$$Q_B = k_f \left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - P_2^2}{GT_f LZf}\right)^{0.5} D^{2.5}\ [scfd]. \tag{4.1}$$

This equation is equivalent to the standard compressible flow equation for gas pipelines provided in [2, Chapter 1] as equation 1-7a. The Crane equation can be sourced at least to Shapiro [3, Chapter 6] as equation (6.42). Below we provide an account of these equations, their equivalence, and the source of their numeric values.

Lemma 1. Equation (1-7) of [2] can be derived from equation (6.42) of [3]

Proof: Equation (6.42) is given as

$$4f\frac{L}{D} = \frac{1-\left(\frac{p_2}{p_1}\right)^2}{kM_1^2} - \ln\left(\frac{p_1}{p_2}\right)^2. \tag{4.2}$$

Note that each term is non-dimensional. Therefore, we may choose any absolute units we would like but momentarily hold off. Note that $f_D = 4f$ where f_D is the *Darcy-Weisbach* friction factor and f is sometimes referred to as the *Fanning* friction factor. By definition in Shapiro, $f = 2\tau_w/(\rho V^2)$ whereas, $f_D = 8\tau_w/(\rho V^2)$ as given in [4, Chapter 9]. Therefore, substituting in f_D into 4.2, we have,

$$kM_1^2 = \frac{1}{f_D\frac{L}{D} + \ln\left(\frac{p_1}{p_2}\right)^2}\left(1-\left(\frac{p_2}{p_1}\right)\right)^2 \tag{4.3}$$

After some algebra and recalling that the *Mach* number is $M = V/c = V/\sqrt{kRT}$, where c is the speed of sound, substituting we have,

$$V_1^2 = \frac{(RT_1/p_1)}{f_D\frac{L}{D} + 2\ln\left(\frac{p_1}{p_2}\right)}\left(\frac{p_1^2 - p_2^2}{p_1}\right) \tag{4.4}$$

$$= \frac{1/\rho_1}{f_D\frac{L}{D} + 2\ln\left(\frac{p_1}{p_2}\right)}\left(\frac{p_1^2 - p_2^2}{p_1}\right) \tag{4.5}$$

Define w as mass flow so that $w = \rho AV$. Define the specific volume as $\bar{V} = 1/\rho$. Then, multiply both sides of (4.4) by $(\rho_1 A)^2$, where A is the cross sectional area,

$$(\rho_1 A)^2 V_1^2 = w^2 = \frac{A^2}{\bar{V}_1\left(f_D\frac{L}{D} + 2\ln\left(\frac{p_1}{p_2}\right)\right)}\left(\frac{p_1^2 - p_2^2}{p_1}\right) \tag{4.6}$$

Now we shall establish the physical units as those used in the Crane equation. Let pressures be given in PSIA, lengths be given in feet, density be given in lbm/ft^3 and mass flow in lbm/s. In the following equation, we will put physical units in brackets. Consider the units of (4.6):

$$w^2 \quad \left[\frac{lbm}{s}\right]^2 \tag{4.7}$$

$$= \frac{A^2 \quad [ft^2]^2 \left(\frac{p_1^2 \quad [lbf/in^2]^2 - p_2^2 \quad [lbf/in^2]^2}{p_1 \quad [lbf/in^2]}\right)}{\bar{V}_1 \quad [ft^3/lbm] \left(f_D \frac{L}{D} \frac{[ft]}{[ft]} + 2\ln\left(\frac{p_1 \quad [lbf/in^2]}{p_2 \quad [lbf/in^2]}\right)\right)} \tag{4.8}$$

$$= \frac{A^2 \quad \left(\frac{p_1^2 - p_2^2}{p_1}\right)}{\bar{V}_1 \left(f_D \frac{L}{D} + 2\ln\left(\frac{p_1}{p_2}\right)\right)} \left[\frac{lbm \cdot lbf \cdot ft}{in^2}\right] \tag{4.9}$$

$$= \frac{144A^2 \left(\frac{p_1^2 - p_2^2}{p_1}\right)}{\bar{V}_1 \left(f_D \frac{L}{D} + 2\ln\left(\frac{p_1}{p_2}\right)\right)} \left[\frac{lbm \cdot lbf}{ft}\right] \tag{4.10}$$

Finally, recalling that $1 \ [lbf] = 32.174 \ [lbm \cdot ft/s^2] = g \ [lbm \cdot ft/s^2]$, we have,

$$w^2 \quad \left[\frac{lbm}{s}\right]^2 = \frac{144gA^2 \left(\frac{p_1^2 - p_2^2}{p_1}\right)}{\bar{V}_1 \left(f_D \frac{L}{D} + 2\ln\left(\frac{p_1}{p_2}\right)\right)} \left[\frac{lbm}{s}\right]^2 \tag{4.11}$$

Equation 4.11 is precisely equation 1-6 in [2]. Adding the assumption that acceleration can be neglected drops the term $2\ln(p1/p2)$:

$$w^2 = \frac{144gDA^2}{\bar{V}_1 f_D L}\left(\frac{p_1^2 - p_2^2}{p_1}\right) \tag{4.12}$$

and we have arrived at equation 1-7 as desired. □

Showing the equivalence of the general flow equation expressed as a mass flow compared with volumetric flow is hardly a lemma, however, we will state it here and prove it for the sake of completeness, as we will end by showing that the equations found in Crane and Menon are identical.

Lemma 2. Equation (1-7) and (1-7a) in [2, Chapter 1] are equivalent.

Proof: Consider (4.12) with mass flow w. Dividing w by ρ_g, the specific gas density, at standard conditions will provide an equation of volumetric flow at standard conditions $[ft^3/s]$. Recall that $\rho_g = S_g \rho_a$ where S_g is the specific gravity and ρ_a is the density of air. Furthermore, $R = 53.3/S_g$ and for an ideal gas, $\rho = p/RT$. However, for the units specified in Crane for $\rho \ [lbm/ft^3]$, we must convert the pressure length scale to feet, which yields $\rho = 144p/RT$. We have,

$$\begin{aligned} q = \frac{w}{\rho_g} &= \sqrt{\frac{144gDA^2\rho_1}{fL(\rho_a S_g)^2}\frac{(p_1^2 - p_2^2)}{p_1}} \\ &= \sqrt{\frac{144gDA^2\rho_1}{fL(\rho_a S_g)^2}\frac{RT}{RT}\frac{(p_1^2 - p_2^2)}{\frac{144}{144}p_1}} \\ &= \sqrt{\frac{144^2 gDA^2}{\rho_a^2 fLS_g^2(53.3/S_g)T}(p_1^2 - p_2^2)} \\ &= \sqrt{\frac{144^2 gDA^2}{53.3\rho_a^2 fLS_g T}(p_1^2 - p_2^2)} \end{aligned} \tag{4.13}$$

Now, $A = (\pi/4)^2 D^4$, and $\rho_a = 0.0764$ at standard conditions is used in Crane [2, Appendix B]. Then, substituting these and $g = 32.2$ into (4.13) and simplifying, we have,

$$q = \sqrt{\frac{144^2 \cdot 32.2 \cdot \pi^2}{16 \cdot 53.3 \cdot (0.0767)^2}}\sqrt{\frac{D^5}{fLS_g T}(p_1^2 - p_2^2)} \tag{4.14}$$

Finally, we must adjust the units of L and D. $L \ [ft] = 5280L_m \ [miles]$ and $D \ [ft] = 12d \ [in]$. Therefore, (4.14) becomes

$$\begin{aligned} q &= \sqrt{\frac{144^2 \cdot 32.2 \cdot \pi^2}{16 \cdot 53.3 \cdot (0.0767)^2}}\sqrt{\frac{(\frac{12d}{12})^5}{f\frac{5280L_m}{5280}S_g T}(p_1^2 - p_2^2)} \\ &= \sqrt{\frac{144^2 \cdot 32.2 \cdot \pi^2}{16 \cdot 53.3 \cdot (0.0767)^2 \cdot 5280 \cdot 12^5}}\sqrt{\frac{d^5}{fL_m S_g T}(p_1^2 - p_2^2)} \end{aligned} \tag{4.15}$$

$$\approx 0.0317\sqrt{\frac{d^5}{fL_m S_g T}(p_1^2 - p_2^2)} \tag{4.16}$$

Finally, to change the flow units from $[ft^3/s]$ to $[ft^3/hr]$ we multiply by 3600:

$$q_h = 114.2\sqrt{\frac{(p_1^2 - p_2^2)d^5}{fL_m TS_g}} \tag{4.17}$$

which yields equation (1-7a) as desired. □

Theorem 2. Equation (1-7a) of [2, Chapter 1] and equation (2.2) of [1] are equivalent.

Proof: Since $T_B = 520 \ [^\circ R]$ and $P_B = 14.7 \ [psia]$, we have have

$$\frac{77.54}{24} \cdot \frac{520}{14.7} \approx 114.2$$

where the division by 24 is to convert from per day to per hour. The remaining piece is bringing in the compressibility factor Z. Crane assumes ideal gas whereas Menon uses real gas. The correction factor alters the ideal gas equation from $\rho = P/RT$ to $\rho = P/ZRT$. This manifests in the second line of equations given in (4.13), where instead of substituting in

$1 = RT/RT$ we substitute $1 = ZRT/ZRT$, which leaves Z in the denominator.

Thus, with these substitutions, equation (2.2) of [1, Chapter 2] given in (4.1) becomes equation (1-7a) of [2, Chapter 1] given in (4.17).

While the above is accurate, it is not entirely satisfying. Consider (4.15), where we bring back $\rho_a = P/RT$. Note that $\rho_a = 0.0767 \;\; [lbm/ft^3] = 144P/R_aT$ and $R_a = 53.3$:

$$\begin{aligned} q &= \sqrt{\frac{144^2 \cdot 32.2 \cdot \pi^2}{16 \cdot 53.3 \cdot 5280 \cdot 12^5}} \sqrt{\frac{(p_1^2 - p_2^2)d^5}{\rho_a^2 f L_m S_g T}} \\ &= \sqrt{\frac{144^2 \cdot 32.2 \cdot \pi^2}{16 \cdot 53.3 \cdot 5280 \cdot 12^5}} \sqrt{\frac{(p_1^2 - p_2^2)d^5}{\left(\frac{144P_B}{R_aT_B}\right)^2 f L_m S_g T}} \\ &= \sqrt{\frac{53.3 \cdot 32.2 \cdot \pi^2}{16 \cdot 5280 \cdot 12^5}} \left(\frac{T_B}{P_B}\right) \sqrt{\frac{(p_1^2 - p_2^2)d^5}{f L_m S_g T}} \\ &(\approx 8.9766 \times 10^{-4}) \left(\frac{T_B}{P_B}\right) \sqrt{\frac{(p_1^2 - p_2^2)d^5}{f L_m S_g T}} \end{aligned} \tag{4.18}$$

and since q has units $[ft^3/s]$ at standard conditions, we must multiply (4.18) by 8.64×10^4 which gives the final result $Q \;\; [ft^3/day]$ at standard condtions:

$$Q = 77.76 \left(\frac{T_B}{P_B}\right) \sqrt{\frac{(p_1^2 - p_2^2)d^5}{f L_m S_g T}} \tag{4.19}$$

which is equation (4.1) up to rounding. □

5 RESULTS

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6 CONCLUSION

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ACKNOWLEDGMENTS

Acknowledgements should be placed after the conclusion and before the references section. This is where reference to any grant numbers or supporting bodies should be included.

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[1] E. S. Menon, *Gas Pipeline Hydraulics*. CRC Taylor and Francis Group, 2005.

[2] C. Crane, “Flow of fluids through valves, fittings, and pipe-technical paper, no. 410,” 1980.

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[4] M. O. H. Rothmayer, *Fundamentals of Fluid Mechanics*. Wiley, 7th ed., 2013.

APPENDICES

Additional material, e.g. mathematical derivations, tables and figures larger than half a page that may interrupt the flow of your paper’s argument should form a separate Appendix section.

AUTHOR BIOGRAPHIES

Author One - has this background.
Author Two - has that background.
Author Three - has another background.

Table 3 Example wide single-column table in a twocolumn document.

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cell 1	cell 2	cell 3
cell 1	cell 2	cell 3

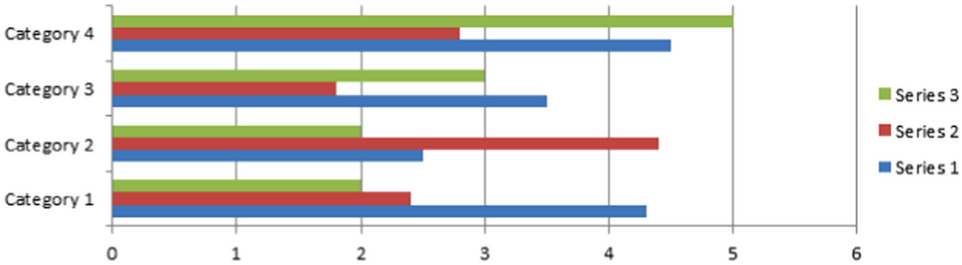

Figure 2 **Sample graph spaning two columns and using .eps style instead of .png**