Efficient Pneumatic Conveying Dense Phase vs. Dilute Phase: How Being Accurate is More Cost Effective Than Being Conservative

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INTRODUCTION

In the coal combustion products realm there is a growing trend towards requiring dilute phase pneumatic conveying as a rule. The first hurdle to meet with this mindset is to actually define dilute phase. A widely accepted definition available for dilute phase flow is a two phase flow where all of the conveyed particles are carried in suspension [1]. From a practical standpoint this definition is useless as, short of installing sections of transparent pipe, there is no way to verify whether 100% of the conveyed material is being carried in suspension. The next logical step is to determine some measurable properties to serve as the delineation between dense and dilute phase. Commonly gas velocities and pressure drops are selected to serve this purpose. The problem with such a definition is that for it to hold true for a range of materials, the values need to be very conservative. For example, it is not unusual to hear a plant engineer or operator state that a pressure conveying system that operates with air velocities over 3000 ft/min or overall pressure drops of less than about 15 psi is indeed a dilute phase system. The question you should be asking yourself is “Is this cost effective?”

PROBLEM

From the viewpoint of a design and supply firm overly conservative design requirements are wonderful. At such elevated airflow rates one needs little to no knowledge of the material. At 3000+ ft/min one could successfully convey iron powder through a pipeline so fly ash with its characteristic permeability, air retention, and ease of conveying can certainly be moved with little concern [2]. So now I can cut costs by not having to invest in the expertise of my design engineers. To meet the higher velocities I also get to supply much larger blowers than may be necessary; another increase in profit margin. To keep the pressure drop within range at these elevated specified velocities larger pipe is usually necessary. Now I am providing more pounds of steel per foot of conveyance thanks to increased pipe sizes and beefier supports required to keep it all in the air. As pipeline erosion is a function of airflow proportional to the range of velocity squared to velocity cubed, a dramatically increased erosion rate at and near fittings should be expected [3]. Again, as a design and supply firm I see dollar signs. Now I can provide hardened fittings, hardened pipe, and “severe service” valves. The beauty of these components is, although they will slow the erosion rate, they do not stop the actual damage mechanism. So they WILL wear out and if I can convince the client that they need MY proprietary fittings and valves they will have to come back to me to purchase the replacements. This aspect can be so lucrative that I may be willing to actually sacrifice profit on the initial project just to get my foot in the door and enrich myself as a parts provider. It should be obvious that blindly setting such conservative limits stacks the deck in the design and supply firm’s favor. As the customer who is spending hundreds of thousands, if not millions, of dollars on such products shouldn’t you be provided with a system that is designed with efficiency and reliability (i.e., your best interest) in mind?

STUDY

This study examines a recent proposal where the customer requested a system to be designed to a conservative dilute phase specification. The system was designed and quoted per the customer specification; however, an alternative system design was quoted for comparison by the customer applying a hybrid phase approach tailored to the customer’s performance requirements. The following paragraphs will describe the system layout, design method, final design differences, and financial differences.

	CUSTOMER SPEC	**INTERNAL SPEC**
Pressure Conveying Overall Pressure Drop Requirement	Less than 15 psi	Within the capabilities of a commonly available blower or compressor.
Pressure Conveying Minimum Air Velocity	3,000 ft/min	2,000 ft/min (Considered conservative without the benefit of a full scale material analysis)
Vacuum Conveying Overall Pressure Drop Requirement	Must fall within the capabilities of a commonly available vacuum blower	Must fall within the capabilities of a commonly available vacuum blower
Vacuum Conveying Minimum Air Velocity	3,500 ft/min	2,500 ft/min (Considered conservative without the benefit of a full scale material analysis)

TABLE 1: DESIGN SPECIFICATIONS

SYSTEM DESCRIPTION

The system proposed is a combination vacuum and pressure conveying system. Figure 1 shows the plan view of the equipment locations and pipe routing. The target conveying rate is 34 tons of fly ash per hour. The vacuum conveying system begins at the base of the unit baghouse where the ash/air mixture is “pulled” by vacuum from the baghouse hoppers into the collector, which feeds an airlock discharging into the transfer tank. See Appendix A for flow diagram. The pipe route includes 316 feet of horizontal pipe, 67 feet of vertical pipe, and eight 90 degree elbows. The transfer tank fills the transfer vessels where the pressure conveying system takes over and compressed air is used to “push” the ash/air mixture to the storage silo. See Appendix B for flow diagram. The pressure conveying route consists of 3108 feet of horizontal pipe, 130 feet of vertical pipe, and eight 90 degree elbows.

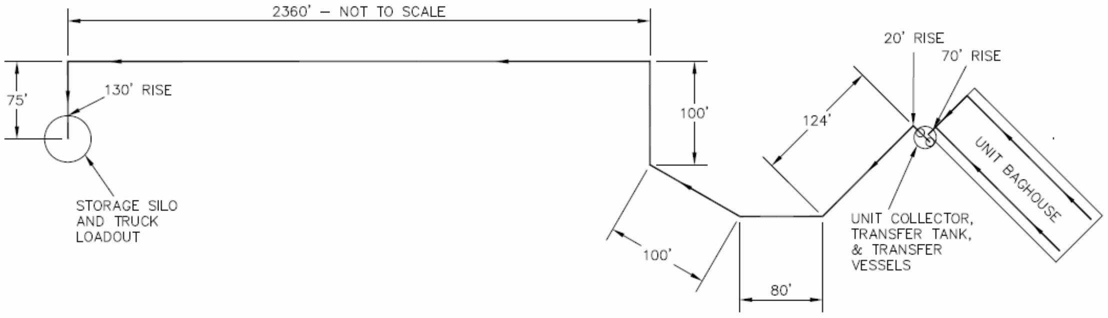


FIGURE 1: Plan View of Piping Route

DESIGN OVERVIEW

A critical parameter of a pneumatic conveying system design is the minimum pickup velocity of the material [4]. This is the minimum air velocity at which an aerated material will join the air flow [5]. It is the critical nature of this parameter that influences many designers to be overly conservative in its definition. Material testing is the best way to get a definitive range for this parameter. For preliminary design purposes previous material testing of a very similar material can be used with the addition of a reasonable safety factor until testing of actual system material can be performed. The minimum pickup velocity is determined as part of the material lab testing. Sample material is conveyed through the system detailed in Figure 2: Lab Conveying Loop Schematic.

INSTRUMENT LABEL	RANGE	DESCRIPTION
PT 0	0–150 PSIG	UPSTREAM OF ORIFICE PRESSURE READING FOR FLOW CALCULATION
DPT 1	0–150 " W.G.	DIFFERENTIAL PRESSURE ACROSS ORIFICE FOR FLOW CALCULATION
PT 2	0–75 PSIG	TOTAL CONVEYING LINE PRESSURE
TT3	0–350 F	TEMPERATURE OF CONVEYING AIR FOR FLOW CALCULATION
DPT 4	0–100 PSIG	DIFFERENTIAL PRESSURE ACROSS TOTAL CONVEYING LOOP
DPT 5	0–100 PSIG	DIFFERENTIAL PRESSURE ACROSS VERTICAL RISE
DPT 6	0–100 PSIG	DIFFERENTIAL PRESSURE ACROSS FIRST CONVEYING LOOP
PT 7	0–75 PSIG	PRESSURE IN CONVEYING PIPE AT END OF FIRST CONVEYING LOOP
WT 9	0–300 LBS	WEIGHT OF MATERIAL IN COLLECTOR

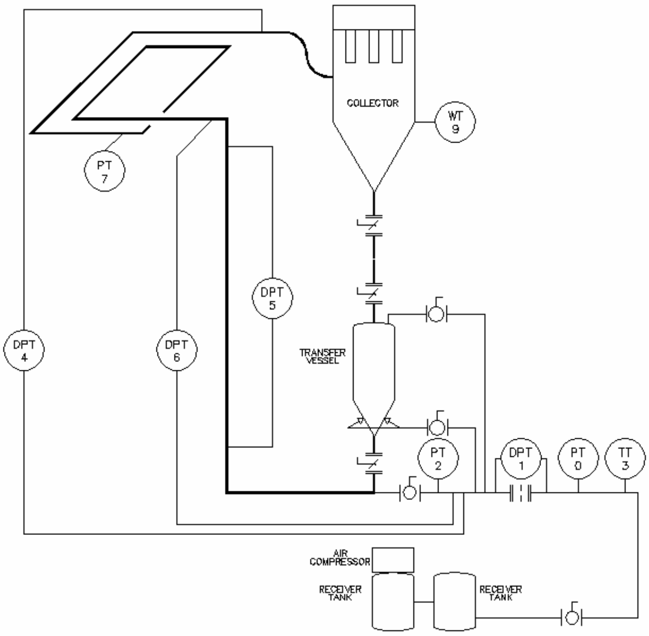


FIGURE 2: LAB CONVEYING LOOP SCHEMATIC

The material is conveyed through the system in a series of runs at varying rates of material feed and transfer air supply while taking pressure readings at the various locations as indicated in Figure 2. After completion, a chart is assembled plotting pressure drop values with respect to air and material flow rates (See Figure 3).

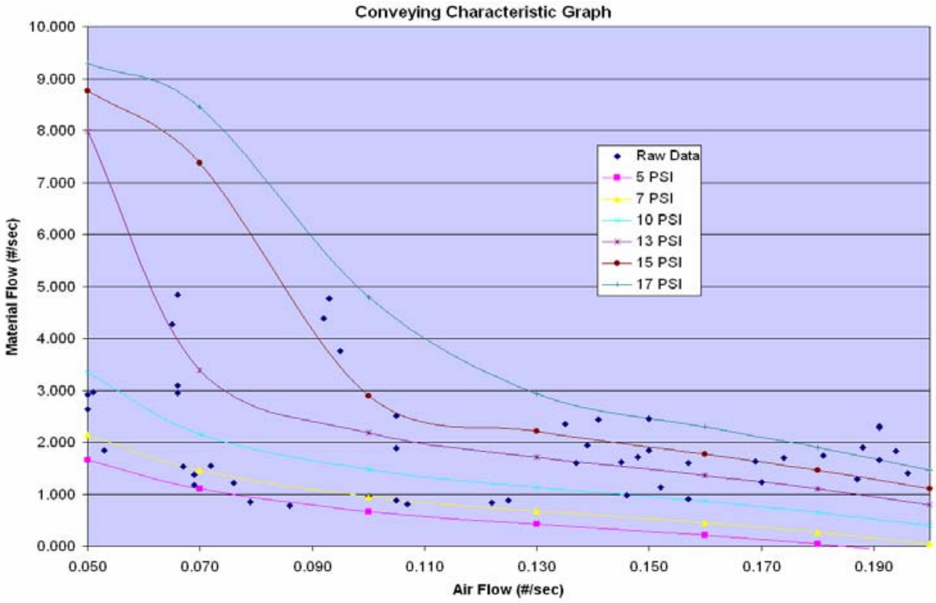
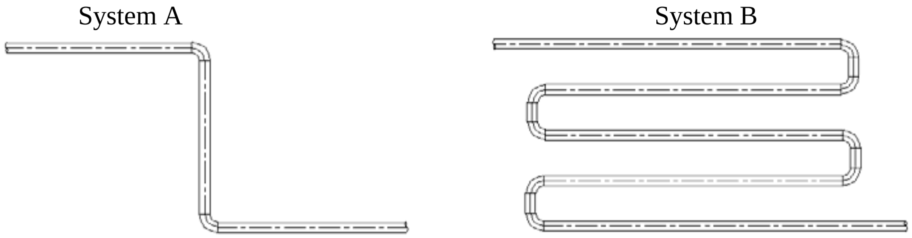


FIGURE 3: ISO-PRESSURE LINES FROM RAW DATA REGRESSION

From here the lab scale procedure detailed by David Mills (Mills 2004, Mills 2009) is utilized to “scale” the material/air flows and pressure drops from the relatively small lab system to the final full scale system design. It is not the intention of this study to present this method in detail. However, in summary, the method relies on two well proven assumptions which are logically and iteratively applied. The first assumption is that for two piping segments of equal diameter, equal air mass flow rates, and equal pressure drop attributed to material flow the ratio of the material mass flow rates equals the ratio of their lengths (See Figure 4). The second assumption is that for two piping segments of equal solids loading ratios (mass flow rate of material divided by mass flow rate of air) and equal average velocities the pressure drop attributed to material flow rate will be equal per unit length (See Figure 4).

ASSUMPTION #1



IF: $\dot{m}_{a,A} = \dot{m}_{a,B}$ and $\Delta P_{p,A} = \Delta P_{p,B}$

THEN: $\dfrac{\dot{m}_{p,A}}{\dot{m}_{p,B}} = \dfrac{L_{e,B}}{L_{e,A}}$

ASSUMPTION #2

PER UNIT LENGTH L

IF: $SLR_A = SLR_B$ and $C_{i,A} = C_{i,B}$

THEN: $\dfrac{\Delta P_{p,A}}{L} = \dfrac{\Delta P_{p,B}}{L} =$ Constant

FIGURE 4: LAB SCALE PROCEDURE ASSUMPTIONS

The result of the procedure is a series of graphs similar to Figure 5 from which a pressure drop of a piping segment can be determined at a multitude of combinations of air and material flow rates. These values are collected to determine the final system requirements.

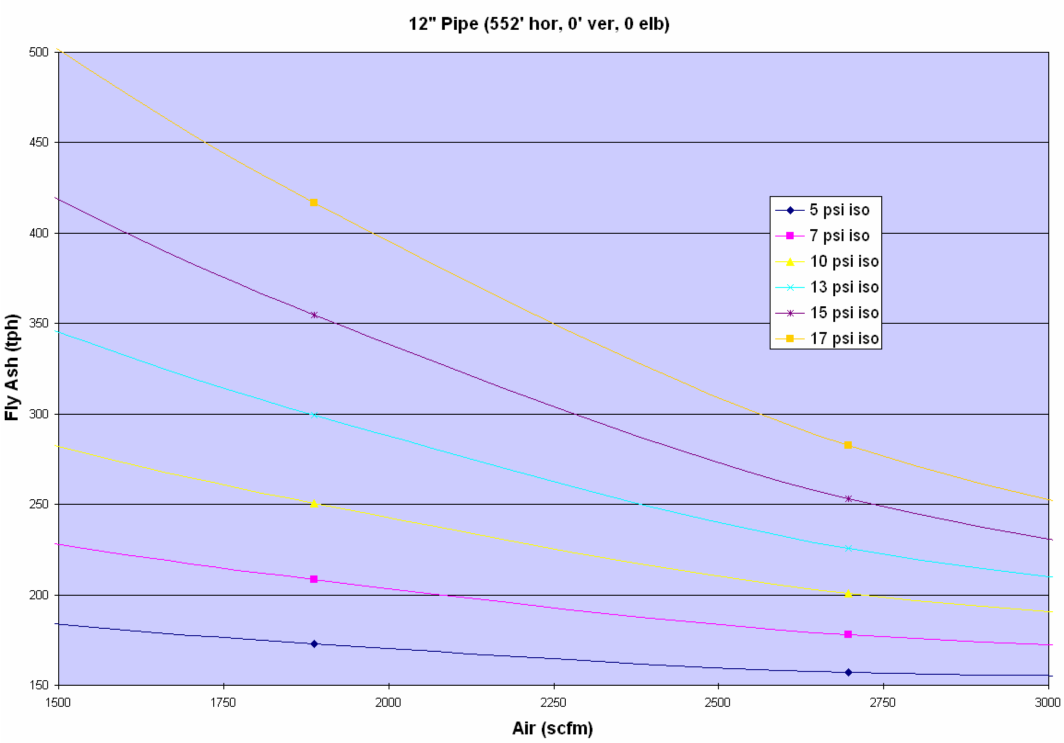


FIGURE 5: SYSTEM PERFORMANCE OF PIPING SEGMENT

RESULTS

For the two designs being reviewed in this study the air and pipe sizing requirements as well as purchase/operating costs are as follows.

	Air Requirements (ICFM)	**Piping Requirements**
VACUUM SYSTEM		
Customer Spec	4207 @ 17.8”Hg	100’ of 8” Pipe 213’ of 10” Pipe 70’ of 12” Pipe
Firm Spec	2783 @ 17.1”Hg	100’ of 8” Pipe 265’ of 10” Pipe 18’ of 12” Pipe
PRESSURE SYSTEM		
Customer Spec	3465 @ 14.4 psig	1221’ of 12” Pipe 2012’ of 14” Pipe
Firm Spec	1216 @ 33.0 psig	25’ of 6” Pipe 1196’ of 8” Pipe 2012’ of 10” Pipe

TABLE 2: DESIGN AIR AND PIPING REQUIREMENTS

	Up-Front Cost (dollars)	**Operating Cost* (dollars/year)**
CUSTOMER SPEC		
Piping	270,403	0
Vacuum Blower (250 HP)	139,941	82,125
Pressure Blower (400HP)	84,131	131,400
Silo Air Cleaning and Relief	82,505	0
Total	*576,980*	*213,525*
FIRM SPEC		
Piping	223,829	0
Vacuum Blower (200 HP)	113,445	65,700
Compressor (250 HP)	114,400	82,125
Silo Air Cleaning and Relief	58,340	0
Total	*510,014*	*147,825*

***Power cost calculated based on 12 hours of operation per day, 365 days per year at $0.10/kWh*

TABLE 3: DESIGN COST SUMMARY

CONCLUSION

Reviewing Table 3 from the results shows a dramatic cost savings when choosing to back off of the overly conservative dilute phase specification. There is an up-front savings of $66,966 and a yearly operating cost savings of $65,700.

It should be noted that these results may not be typical. There are certainly times when a dilute phase system will be the clear winner when performing such a cost comparison. The driving factor for this is commonly the high up-front cost of a compressor versus a pressure blower. The point of this study is not to declare one design to be superior to the other. The purpose is to show that there are options to what is becoming the growing norm of dilute phase only specification.

So as an owner-operator how does one protect their interests and ensure that the system you are paying for is being designed to maximize efficiency and reliability rather than the design and supply firm’s profit?

- Ask for a guarantee of conveying rate. Reliable design firms will have the confidence in their design methods to supply this.
- Do not paint your designer into a corner with arbitrary velocity or pressure drop limits.
- Check their references of systems in place and operator’s experiences.
- Have the firm run a material analysis to establish specific material characteristics. The additional up front cost yields the benefit of increased system efficiency which will pay dividends during the life of the plant.
- When requesting a quote, ask for both dilute and dense phase options. This is not always possible but at a minimum it is a good conversation starter and will give you a feel for the firm’s capabilities.

- Insist on components available from more than one source when possible. The best way to keep cost down is through competition.

NOMENCLATURE

C	Velocity	$\frac{ft}{sec}$
L	Pipeline Length	ft
$\dot{m}$	Mass Flow Rate	$\frac{lbm}{min}$
P	Conveying Air Pressure	psi

Subscripts

a	Conveying Air
e	Equivalent Value
i	Isentropic
p	Product
A,B	Actual Conditions

Prefixes

Δ	Difference in Value

REFERENCES

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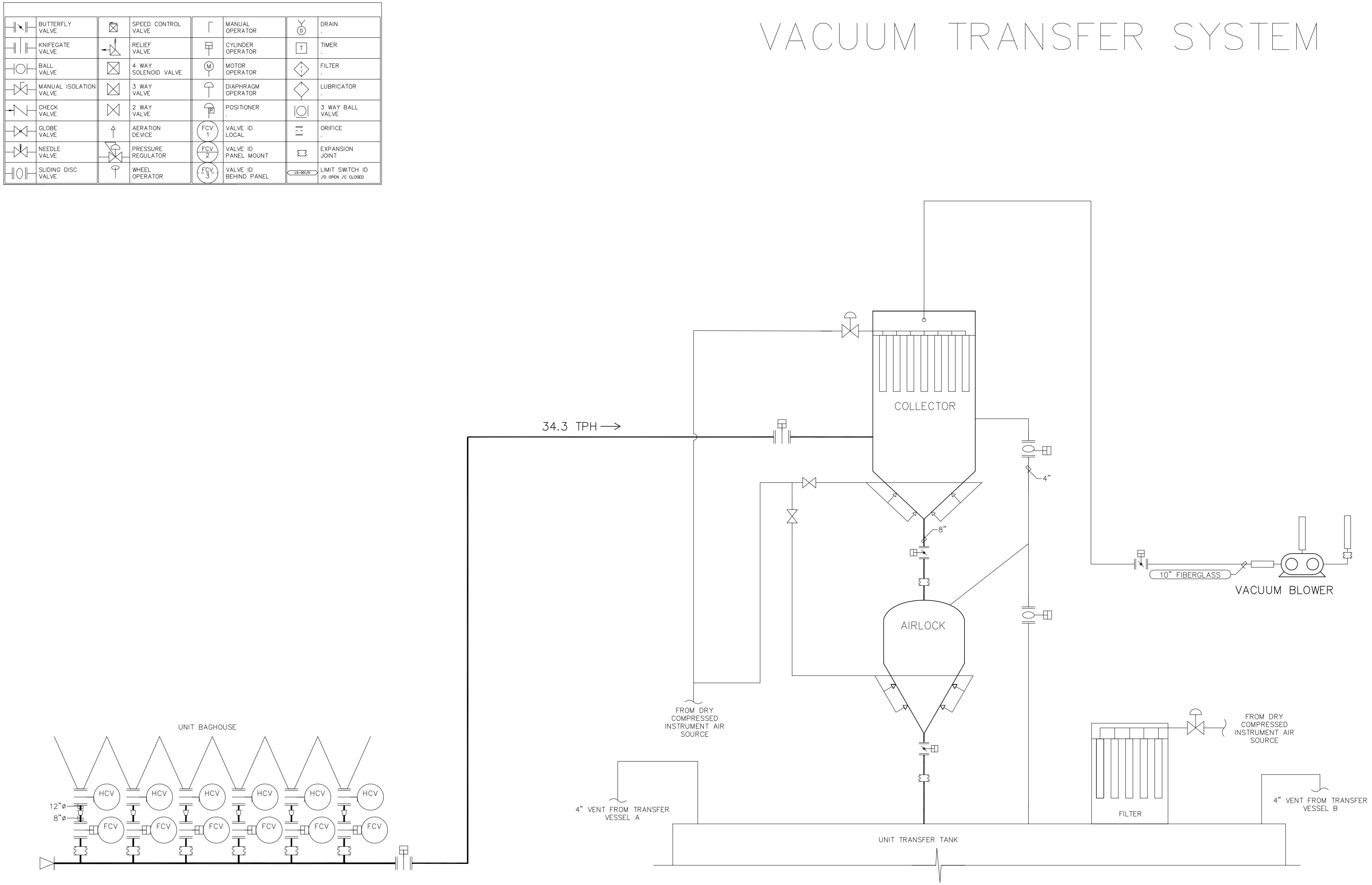
APPENDIX A
Vacuum System Flow Diagram

VACUUM TRANSFER SYSTEM



APPENDIX B
Pressure System Flow Diagram

PRESSURE TRANSFER SYSTEM