Theory and Design of Dilute Phase Pneumatic Conveying Systems

Introduction

This article describes the theory and calculation method for designing dilute phase pneumatic conveying systems. It is based on the work of Dr. F.A. ZENZ and Dr. D.F. OTHMER as described by them in their book "Fluidization and Fluid-Particle Systems" published in 1960 (Ref. 1). This method was later modified by Dr. ZENZ based on his research work during the 70's and 80's and published in the proceedings of the Particle Science Research Institute (PSRI). Although, several other methods have been published since then, this method has been used widely and has been found to be within about 10% of the actual measured pressure drop.

This calculation method can be used to perform the following functions:

- Design of new systems.

- Prediction of maximum solids transfer rate using existing gas supply and conveying line.

- Calculations for gas flow needed for a specific solids transfer rate, using an existing conveying line.

- Sizing of the conveying line for a specific solids transfer rate using existing gas supply.

- Modifying any of the above by increasing the line diameter along the conveying line to maintain a specific conveying velocity or a terminal velocity, or a maximum conveying pressure.

1. Basis for the Calculation Method

The calculations for the design of a dilute phase conveying system are based on determining the pressure drop that is generated in the system due to the flow of gas and solids. ZENZ and OTHMER state that this pressure drop, for both dilute and dense phase conveying, is composed of six effective forces:

1. Friction of the gas against the pipe wall.

2. Force required for moving the solids mass through the conveying pipeline.

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3. In vertical pipes the force required to support the weight of the solids.

4. In vertical pipes the force required to support the weight of the gas.

5. Force required to accelerate the solids.

6. Friction between the pipe and the solids.

Compared with dense phase, friction between the pipe and the solids (Item 6) in dilute phase conveying is usually negligible and it can be ignored.

2. Calculation Method

In their book published in 1960, ZENZ and OTHMER give the following two equations for calculating pressure drop in dilute phase conveying systems:

Horizontal Lines:

$$\Delta P_{T(HOZ)} = \frac{V_g^2 \cdot \rho_g}{2 \cdot g} + \frac{W \cdot V_p}{g} + \frac{2 \cdot f \cdot \rho_g \cdot V_g^2 \cdot L}{g \cdot D} \cdot \left(1 + \frac{f_p \cdot V_p}{f \cdot V_g} \cdot \frac{W}{V_g \cdot \rho_g}\right)$$

Vertical Lines:

$$\Delta P_{T(VERT)} = \Delta P_{T(HOZ)} + \frac{W \cdot L}{V_p}$$

For horizontal lines, the first term is the pressure drop due to the acceleration of gas, the second term is the pressure drop due to the acceleration of solids, the third term is the pressure drop due to friction between the gas and the pipe wall, and the fourth term is the pressure drop due to the flow of solids through the pipeline.

For vertical flows another term ($W \cdot L / V_p$) is added to represent the weight of the supported solids in the vertical line.

The nomenclature used in the above equations is given below:

V_g = Gas velocity

ρ_g = Gas density

W = Solids mass velocity, [lbs/sec·ft^2]

V_p = Particle velocity

f = Fanning friction factor

L = Length of pipeline

D = Pipeline inside diameter

f_p = Solids friction factor

For pressure drop due to solids friction, ZENZ and OTHMER in their book explained that some of the earlier investigations had concluded that the term $(f_p \cdot V_p)/(f \cdot V_g)$ could be ignored but that the use of this term, in general, will predict pressure drops greater than those observed and thus can be considered conservative for design purposes. Further research on this topic was carried out by ZENZ while he was at PSRI and he concluded that this term should be replaced by a constant (K) because this term was dependent upon the physical properties of the solids being conveyed. His investigation also concluded that because of many variables it was very difficult to develop an accurate correlation for calculating the value of K and therefore, the value of K should be back-calculated from the actual pressure drop data obtained from lab or plant tests.

Based on this work the term for solids pressure drop was changed to:

$$\Delta P_s = \Delta P_g \cdot K \cdot \frac{W}{V_g \cdot \rho_g} = \Delta P_g \cdot K \cdot R$$

where,

ΔP_s = pressure drop due to solids flow

ΔP_g = pressure drop due to gas flow

K = constant depending upon solids physical and frictional properties

R = ratio of solids to gas mass flow rates

The next step is to develop a single equation for calculating the total pressure drop in a conveying system that may have both horizontal and vertical lines. In addition, a term ΔP_{misc} was added to account for pressure drop in any equipment such as a dust collector that may be required at the end of the conveying line.

This equation consisting of six pressure drop terms is given below:

$$\Delta P_T = \Delta P_{acc} + \Delta P_g + \Delta P_s + \Delta H_g + \Delta H_s + \Delta P_{misc}$$

where,

ΔP_T = total pressure drop in the system.

ΔP_{acc} = Pressure drop due to acceleration of the solids from their "at rest" condition at the pick-up point to their conveying velocity up to their exit from the conveying system.

ΔP_g = Pressure drop of gas due to frictional losses between the gas and the pipe wall.

ΔP_s = Pressure drop of solids through the pipeline.

ΔH_g = Pressure drop due to elevation of gas in vertical pipe.

ΔH_s = Pressure drop due to elevation of solids in vertical pipe.

ΔP_{misc} = Pressure drop due to miscellaneous equipment.

These six pressure drop terms given above are related to the two pressure drop equations given by ZENZ and OTHMER. These terms are then converted to the units that are commonly used in pneumatic conveying systems, resulting in the following equations where pressure drop is expressed in lbs/square inch.

Eq. 1: Pressure drop due to acceleration of the solids from their "at rest" condition at the pick-up point to the conveying velocity up to the exit from the conveying system:

$$\Delta P_{acc} = \frac{W \cdot V_p}{144 \cdot g} = \frac{W \cdot V_p}{4640}$$

Eq. 2: Pressure drop of gas due to frictional losses between gas and the conveying pipeline and in any bends, diverter valves, and flexible hoses that may be in the pipeline:

$$\Delta P_g = \frac{4f \cdot L \cdot \rho_g \cdot V_g^2}{2g \cdot D \cdot 144}$$

$$= \frac{4f \cdot L \cdot \rho_g \cdot V_g^2}{9266 \cdot D}$$

Note: In the above expression, the term "L" is the length of the straight sections of the pipeline and is the "equivalent length" of the bends, diverter valves and flexible hoses.

Eq. 3: Pressure drop due to friction between the solids and the conveying pipeline, bends, diverter valves, and flexible hoses:

$$\Delta P_s = \Delta P_g \cdot K \cdot R \quad \text{(modified Zenz equation)}$$

Eq. 4: Pressure drop due to elevation of gas by ΔZ feet:

$$\Delta H_g = \frac{\Delta Z \cdot \rho_g}{144 \cdot g_c}$$

Eq. 5: Pressure drop due to elevation of solids by ΔZ feet.

$$\Delta H_s = \frac{\Delta Z \cdot W \cdot g}{144 \cdot V_p \cdot g_c}$$

Eq. 6: Pressure drop due to miscellaneous equipment in the conveying system.

$$= \Delta H_{misc} \text{ (It is a term that is not calculated but is entered as input data in the calculations). This term is a constant.}$$

Nomenclature

The nomenclature and the units that are used in the above six equations are given below:

D = Pipe inside diameter (ft)

f = Fanning friction factor

g = Acceleration due to gravity (32.2 ft/sec^2)

g_c = Constant (32.174 ft-lb/lb-sec^2)

K = Friction multiplier for the solids conveyed

L = Pipe equivalent length (ft)

R = Solids to gas mass flow ratio (lb/lb)

V_g = Gas velocity (ft/sec)

V_p = Particle velocity (ft/sec)

W = Solids line loading (lbs/sec·ft^2)

Z = Elevation change in conveying line (ft)

ρ_g = Gas density (lbs/ft^3)

To solve the above equations the value of the following terms has to be determined:

f = Fanning friction factor

K = Friction multiplier

L = Pipe equivalent length

V_p = Solids velocity

R = Solids to Gas ratio

These values are determined as follows:

2.1   Fanning Friction Factor f

The Reynold's number (N_{Re}) is first calculated

$$N_{Re} = \frac{D \cdot V_g \cdot \rho_g}{\mu_g}$$

where μ_g is the gas viscosity in lbs/(ft·sec)

After this, the Fanning friction factor is calculated using the following equation developed from the charts given in CRANE'S Technical Paper No. 410 (pages A-23, A24) on the "Flow of Fluids".

Eq. 7:

$$f = \frac{0.331}{\log_n \left[\frac{\varepsilon}{3.7 \cdot D} + \left(\frac{7}{N_{Re}} \right) \right]^2}$$

where ε is the pipe roughness factor. Pipe roughness factor depends on if the pipe is internally smooth, rough, or very rough. The value of this factor based on test data is given below:

for internally smooth pipes, $\varepsilon = 0.00015$;

for shot-peened pipes, $\varepsilon = 0.0005$;

2.2   Friction Multiplier (K)

The value of the Friction Multiplier (K) is not calculated but is determined experimentally or retrieved from data bank. Its value is different for different materials. Its range is typically 0.4 to 4.0

2.3   Pipe Equivalent Length (L)

For straight pipes use the actual length of the pipe.

For components such as bends, diverter valves, and flexible hoses, use their equivalent length expressed in pipe diameters of the conveying pipe. Typical equivalent length values are given below:

Component:	Equivalent Length
Bends 90° bend, long radius, (10 to 1 radius to diameter ratio):	40, or 20 ft whichever is more
Diverter Valves 45 degree divert angle: 30 degree divert angle:	 20 10
Flexible Hoses Stainless steel, with lined interior: Rubber or vinyl hose:	 3 x pipe length 5 x pipe length
For bends that are less than 90°, use equivalent length as: $= 40 \cdot \dfrac{\text{Degree of Bend}}{90}$	

For special bends such as short radius bends, Hammerteck, Gamma, pocket-T's, etc., increase the value of 40 to a higher number. For example, for a typical conveying system with about 5 bends increase the calculated pressure drop value by 10%. For 10 bends increase it by 20%. These numbers are based on lab tests or plant data.

2.4   Solids Velocity (Vp)

Solids velocity is always less than the gas velocity because of the drag forces between the gas and the solids. This difference is called the slip factor. For most of coarse or hard solids this slip factor is about 0.8, which means that the solids velocity is 80% of the gas velocity. Therefore, for these materials use a solids velocity 20% less than the gas velocity V_g, i.e.

$$V_p = 0.8 \cdot V_g$$

For fine powders solids velocity is closer to the gas velocity. For these materials use a slip factor of 0.9 instead of 0.8. This value generally ranges from 0.7 to 0.95. Lighter and smaller materials have higher values than those of larger and heavier particles.

2.4.1 Solids Velocity in Long Radius Bends

For a 90 degree radius bend, solids velocity at the exit of the bend V_{p2} is 0.8 times the solids velocity at the inlet of the bend V_{p1}. The factor "0.8" is a typical value but it ranges from 0.6 to 0.9 depending upon the properties of the solids. For bends that are less than 90 degrees, the exit velocity V_{p2} is

$$V_{p2} = \left[1 - \frac{\text{Degree of bend}}{90} \cdot (1 - 0.8) \right] \cdot V_{p1}$$

2.4.2 Solids Velocity after Leaving a Bend

After leaving a 90 degree bend, use a default value of 20 pipe diameters to calculate the length of the straight pipe for the solids to re-accelerate to their original velocity at the inlet of the bend (V_{p1}).

2.5   Solids to Air Ratio R

Calculations are based on using the following term as given by ZENZ and OTHMER:

$$R = \frac{W}{V_g \cdot \rho_g} = \frac{m}{A \cdot V_g \cdot \rho_g}$$

Where m is the solids mass flow rate in lbs/sec and A is the cross-sectional area of the pipe in ft^2. The gas mass flow rate in lbs/sec is calculated based on the actual cfm of gas and gas density introduced into the conveying system by the gas mover, and the internal cross-sectional area of the pipe. Gas can be air or any other gas. Use air as default if use of a different gas is not given.

For pressure type conveying systems, reduce the gas mass flow rate by 5% (default value) to account for gas leakage through a rotary valve, if a rotary valve is used to feed the solids. For more accurate results, change this default value by calculating actual rotary valve leakage (both clearance and displacement).

For the gas density term ρ_g, make corrections if the inlet conditions are different from standard conditions (68 °F, 14.7 psia).

2.6   Gas Density along the Conveying Line:

Gas density depends upon gas pressure and gas temperature. For most conveying systems, gas temperature can be assumed to be constant. Therefore, only changes in pressure will change the gas density. Because the pressure either increases or decreases along the conveying line, depending upon whether it is a vacuum system or a pressure system, gas density will also keep on increasing or decreasing. For calculating the pressure drop due the flow of gas, divide the conveying line into small lengths such as 5 or 10 ft, start from the point where inlet gas density is known (such as ambient conditions), and calculate the exit pressure and corresponding gas density for this small

section. Then use this exit gas density as the inlet gas density for the next pipe section. Repeat this procedure until reaching the end of the conveying line. For vacuum systems, start from the pick-up point and end at the blower inlet. For pressure systems, start from the end of the conveying line and return to the pick-up point.

2.7 Addition or Removal of Gas along the Conveying Line

If some conveying systems, gas is added or removed from the conveying system at any point along the route of the conveying line. In this case, re-calculate the gas mass flow and the solids to gas ratio, and use the new gas flow for the pressure drop calculations after this injection point.

3. Calculation Procedure

The procedure given below for running these calculations is based on the Microsoft Excel spreadsheet method.

3.1 Step 1:

The first step is to define the objectives for the calculations and to gather data that is needed for these calculations.

Example: Conveying System Objectives and Design Data:

Let us assume that the main objective for the calculations is to determine the pressure drop in a vacuum type dilute phase pneumatic conveying system conveying polyethylene pellets at 10,000 lbs/hr rate through a proposed conveying line. Assume that the line diameter is 4 inch but that it can be changed if the calculated pressure drop does not fall within the vacuum rating of the conveying blower. Conveying system uses ambient air at standard conditions. Starting from the inlet, the conveying line is 80 feet horizontal, then has a 90 degree long radius bend, then a 40 feet vertical section, then a 90 degree long radius bend, then a 40 feet horizontal section, then a 90 degree horizontal bend, and lastly 10 feet of horizontal pipe. Pipeline is internally scored to prevent streamers. Conveying line material is aluminum. Ambient conditions are 14.7 psia and 25 C. Air density at these conditions is 0.075 lbs/cu ft. Pick-up velocity is 65 ft/sec. Solids velocity is 80% of gas velocity. Solids friction factor is 1.2. Pipeline roughness factor is 0.0005.

3.2 Step 2:

From the equations given above, retrieve the formulae that will be required in the calculations. These formulae are given below:

Formulae used in Calculations:

Gas pressure drop: $\dfrac{4 \cdot f \cdot L \cdot \rho_g \cdot V_g^2}{9266 \cdot D}$

Gas density: $\dfrac{28 \cdot \text{inlet pressure}}{R \cdot T} = \dfrac{28 \cdot \text{inlet pressure}}{19.32 \cdot (\text{inlet temp.} + 273)}$

In the above equation, 28 is the molecular weight of air, inlet pressure is the pressure at the inlet of the pipe section in lbs/inch^2, R is the gas constant in ft·lbs/(lb mole x degrees Rankine), and T is the absolute gas temperature in degrees Rankine at the inlet of the pipe section.

Fanning friction factor: $\dfrac{0.331}{\log_n\left[\dfrac{\varepsilon}{3.7 \cdot D} + \left(\dfrac{7}{N_{Re}}\right)\right]^2}$

Solids acceleration: $\dfrac{W \cdot V_p}{4640}$

Flow of Solids: $\Delta P_g \cdot K \cdot R$

Elevation of gas: $\dfrac{\Delta Z \cdot \rho_g \cdot g}{144 \cdot g_c}$

Elevation of solids: $\dfrac{\Delta Z \cdot W \cdot g}{144 \cdot V_p \cdot g_c}$

Misc. Pressure Drop: Assume that it is in a dust collector at the end of the conveying line and is 0.2 psi.

3.3 Step 3:

Enter the input data in a spreadsheet form as shown in worksheets 1 and 2. Enter all of the input data in worksheet 1 except for the conveying pipeline data. Enter the pipeline data as shown in worksheet 2 starting from the beginning of the pipeline and finishing at its end.

Prepare worksheet 3 for running the pressure drop calculations. In this sheet, before starting the calculations, all of the cells will be empty except for the known inlet conditions: gas temperature, inlet gas density, inlet pressure, and inlet gas (pick-up) velocity. Pipeline sections are numbered the same as in worksheet 2.

3.4 Step 4: Calculations

3.4.1 Pressure Drop Calculations

In worksheet 1, calculate the Fanning Friction Factor by entering its formula in the formula bar. Use this friction factor in calculating the pressure drop due to the flow of the gas in worksheet 3. Keep this factor constant in the gas pressure drop calculations for all of the pipe sections.

Now start the pressure drop calculations in worksheet 3 starting from the first pipe section. Enter the formula for the pressure drop due to the flow of gas, $(4 \cdot f \cdot L \cdot \rho_g \cdot V_g^2)/(9266 \cdot D)$, in cell # B2 using cell numbers for the input data. For example, the cell numbers will be as follows:

For f worksheet 1, B16

For L worksheet 2, F2

For ρ_g,   worksheet 3, J2

For V_g,   worksheet 3, N2

For D,   worksheet 2, E2. Divide it by 12 because D is in feet.

Excel will enter the result of this calculation in Cell #B2.

In the same way enter the solids acceleration formula, $W \cdot V_p/4640$, in Cell #C2. For W, enter #C3 and for V_p enter #B10 from worksheet 1. Excel will enter the result in Cell #C2.

Now enter the formula for flow of solids, $\Delta P_g \cdot K \cdot R$, in Cell #D2. For K and R, enter Cell #B14 and Cell #B13 from worksheet 1, respectively. Result will be entered in Cell #D2 in worksheet 3.

Now enter the formula for the elevation of gas, $\Delta Z \cdot \rho_g \cdot g/144 \cdot g_c$, in Cell #E2. Because this pipe section is horizontal as shown in worksheet, this pressure drop will be zero.

Similarly, enter the formula for the elevation of solids, $(\Delta Z \cdot W \cdot g)/(144 \cdot V_p \cdot g_c)$, in Cell #F2. Because this pipe section is horizontal as shown in worksheet #2, this pressure drop will also be zero.

Miscellaneous pressure drop in Cell #G4 will also be zero in this section.

Now add all of the pressure drops in Cell #H2 by using the formula $(= \Sigma(B2,C2,D2,E2,F2,G2))$

3.4.2 Gas Density, Gas Pressure, and Gas Velocity Calculations

First section's outlet gas pressure in Cell #M2 is the difference between the inlet pressure and the pressure drop in this section. In Cell #M2 use the formula, (= Σ(L2- H2))

Outlet gas density is calculated in Cell #K2 by using the formula:

= (28·Outlet Pressure)/(19.32·(Outlet Temp. + 273))

Outlet gas velocity in Cell O2 is calculated by using the formula:

= Inlet gas velocity X (Inlet gas density/outlet gas density).

3.4.3 Calculations for Pipeline Sections 2 to 20

Method for calculations for these sections is the same as for section 1, except that the outlet conditions for the preceding section become the inlet conditions for the next section.

3.5 Step 5

Total pressure drop in the conveying system is totaled by adding the pressure drops in Cells H2 to H21.

As shown in worksheet 3, this pressure drop comes to 7.58 psi. The vacuum blower should be able to handle this pressure. If not, run another calculation using a 6 inch pipeline and by entering 6 in cells E2 to E21 in worksheet 2. No other changes in the input data or the formulae are needed. Compare both of the

results and if the pressure drop in the 6 inch line is too low, use a stepped pipe line starting from 4 inch and increasing to 6 inch about midway in the conveying line.

4. Conclusion

For most process and operating engineers the pressure drop calculation method described in this article should be easy to use, to understand, and to study the effect of different variables on system design. It requires only an understanding of Excel and a basic understanding of pneumatic conveying. This article does not give formulae for the calculation of conveying velocity because this subject has already been covered in various published articles.

References

"Fluidized and Fluid Particle Systems", book by Zenz and Othmer, published in 1960 (Chapters 10 and 11) by Reinhold Publishing Corporation, New York, NY

Research papers published by Dr. F. A. Zenz in the 70's and 80's.

Particle Science Research Institute (PSRI) Reports published by Dr. Zenz

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Appendix 1

Cell Numbers	A	B	C	D
		WORKSHEET NO. 1: CONVEYING SYSTEM INPUT DATA		
1	Type of conveying system	Vacuum type		
2	Material to be conveyed	Polyethylene pellets		
3	Solids Conveying Rate	10,000 lbs/hr	W	
4	Pipeline Material	Aluminum, Schedule 10 pipe, internally scored		
5	Conveying Line Configuration	See Worksheet 2	L	
6	Pipe Inside Diameter	4 inch (d) or 0.333 ft (D)	D	
7	Gas used for conveying	Ambient Air at 25 C and 14.7 psia		
8	Gas Inlet Temperature	25 C	t	
9	Inlet Gas Density	0.075 lbs/cu ft	ρ_g	
10	Gas velocity at inlet of conveying system	65 ft/sec	Vg	Based on Test Data
11	Solids Velocity	0.8 x Vg	Vp	Based on Test Data
12	Gas mass flow rate	Hand calculate based on pipe diameter, gas density, and gas velocity (all at inlet conditions) = 1528 lbs/hr		
13	Solids to Gas mass flow Ratio, R	Hand calculate based on solids conveying rate and gas mass flow rate, lbs/hr (= B3/B12) = 6.54	R	
14	Solids Friction Factor (K)	1.2	K	Based on Test Data
15	Pipe line Roughness Factor	0.0005		Based on Test Data
16	Fanning Friction Factor	Use Excel to calculate based on solids friction factor K, pipe diameter D, and Reynolds Number, using Equation 7 in the formula bar = 0.00592	f	

Appendix 2

Cell No.	A	B	C	D	E	F	G
			WORKSHEET NO. 2 : PIPE LINE SECTIONS DATA				
1	**Section Number**	**Pipe line component**	**Orientation**	**Length in feet**	**Inside Diameter (d), inches**	**Section Equivalent Length (L), feet**	**Cumulative Equivalent Length, feet**
2	1	Pipe	Horizontal	10	4	10	10
3	2	Pipe	Horizontal	10	4	10	20
4	3	Pipe	Horizontal	10	4	10	30
5	4	Pipe	Horizontal	10	4	10	40
6	5	Pipe	Horizontal	10	4	10	50
7	6	Pipe	Horizontal	10	4	10	60
8	7	Pipe	Horizontal	10	4	10	70
9	8	Pipe	Horizontal	10	4	10	80
10	9	90 ° Bend	Horizontal to Vertical	4		20	100
11	10	Pipe	Vertical	10	4	10	110
12	11	Pipe	Vertical	10	4	10	120
13	12	Pipe	Vertical	10	4	10	130
14	13	Pipe	Vertical	10	4	10	140
15	14	90 ° Bend	Vertical to Horizontal	4		20	160
16	15	Pipe	Horizontal	10	4	10	170
17	16	Pipe	Horizontal	10	4	10	180
18	17	Pipe	Horizontal	10	4	10	190
19	18	Pipe	Horizontal	10	4	10	200
20	19	90 ° Bend	Horizontal to Horizontal	4		20	220
21	20	Pipe	Horizontal	10	4	10	230

Appendix 3

Cell No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
		WORKSHEET NO. 3 : PRESSURE DROP CALCULATIONS													
1	Section Number	**PRESSURE DROP IN EACH SECTION, PSI**							Gas temp.	Inlet Gas Density	Outlet Gas Density	Inlet Pressure	Outlet Pressure	Inlet Gas Velocity	Outlet Gas Velocity
		Flow of Gas	Solids Accel.	Flow of Solids	Elevation of Gas	Elevation of Solids	Misc.	Total Pressure Drop in Section	Degrees C	lbs/cu ft	lbs/cu ft	psia	psia	ft/sec	ft/sec
2	1	0,024	0,372	0,194	0,000	0,000		0,589	25	**0,075**	0,071	**14,700**	14,111	**65,00**	67,71
3	2	0,024	0,006	0,199	0,000	0,000		0,229	25	0,071	0,069	14,111	13,882	67,71	68,83
4	3	0,025	0,006	0,202	0,000	0,000		0,233	25	0,069	0,067	13,882	13,649	68,83	70,00
5	4	0,025	0,007	0,205	0,000	0,000		0,237	25	0,067	0,066	13,649	13,412	70,00	71,24
6	5	0,025	0,007	0,209	0,000	0,000		0,242	25	0,066	0,065	13,412	13,170	71,24	72,55
7	6	0,026	0,008	0,213	0,000	0,000		0,247	25	0,065	0,064	13,170	12,923	72,55	73,93
8	7	0,026	0,008	0,217	0,000	0,000		0,252	25	0,064	0,063	12,923	12,671	73,93	75,40
9	8	0,027	0,009	0,222	0,000	0,000		0,257	25	0,063	0,062	12,671	12,414	75,40	76,96
10	9	0,027	0,009	0,226	0,000	0,000		0,263	25	0,062	0,060	12,414	12,151	76,96	78,63
11	10	0,057	0,020	0,468	0,000	0,000		0,544	25	0,060	0,059	12,151	11,607	78,63	82,32
12	11	0,029	0,013	0,243	0,004	0,033		0,323	25	0,059	0,056	11,607	11,284	82,32	84,67
13	12	0,030	0,014	0,250	0,004	0,032		0,330	25	0,056	0,055	11,284	10,954	84,67	87,22
14	13	0,031	0,015	0,258	0,004	0,031		0,339	25	0,055	0,053	10,954	10,615	87,22	90,01
15	14	0,066	0,034	0,541	0,007	0,059		0,708	25	0,053	0,052	10,615	9,907	90,01	96,44
16	15	0,035	0,020	0,285	0,000	0,000		0,340	25	0,052	0,048	9,907	9,567	96,44	99,86
17	16	0,036	0,021	0,296	0,000	0,000		0,353	25	0,048	0,046	9,567	9,214	99,86	103,68
18	17	0,037	0,024	0,308	0,000	0,000		0,369	25	0,046	0,045	9,214	8,845	103,68	108,00
19	18	0,039	0,027	0,321	0,000	0,000		0,387	25	0,045	0,043	8,845	8,458	108,00	112,94
20	19	0,084	0,066	0,690	0,000	0,000		0,840	25	0,043	0,041	8,458	7,618	112,94	125,39
21	20	0,046	0,046	0,376	0,000	0,000	0,200	0,668	25	0,041	0,037	7,618	7,150	125,39	133,59
	Total Pressure Drop							7,550							