Hydrodynamic Studies of Pressurized Fluidized Bed Gasifier of Conical Distributors

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Abstract

This paper aims at measurement of hydrodynamic parameters of cold model of Pressurized Fluidized Bed Gasifier (PFBG) and develops hydrodynamic similarity with the existing hot model PFBG of an IGCC Power plant. In the present experimental work, pilot scale hot model data of PFBG of 168 TPD had been verified by constructing hydrodynamically similar cold model of 2/3rd scale semi-circular. Also pressure measurements at four different heights have been taken for recording pressure fluctuations. It is found that amplitude of pressure fluctuations is related to bubble size and reflect Bed hydrodynamics Experiments have been conducted using different distributor configurations with apex angles of 60^0 and 120^0 which were designed, fabricated and tested in a cold model and the optimised distributor configuration arrived. Experiments were conducted for different materials such as REFRACTORY (of mean particle sizes-0.8) and BOTTOM ASH (of mean particle size- 0.8mm) at different static bed heights (D, 1.5D, 2D) with distributors of apex angles: 60^0, and 120^0. Trends in distributor pressure drop (ΔP_d) and Bed pressure drop (ΔP_{bed}) values in relation to superficial velocity (U_o) have been recorded and formatted into a graph of ΔP_{bed} Vs U_o. Minimum fluidization velocities (U_{mf}) for afore mentioned materials at respective static bed heights with each of two distributors, are then determined from related plots.

It is found that Minimum fluidization velocities (U_{mf}) are decreasing with increase in static bed heights (D, 1.5D, 2D) when the air flow was increasing from zero to maximum. The U_{mf} values are found to be increasing with increase in distributor apex angle (α) from 60^0 to 120^0.

Keywords

Hydrodynamics, Fluidization, Integrated Gasification Combined Cycle (IGCC), Pressurized Fluidized Bed Gasifier (PFBG), Refractory, Bottom Ash, Distributors of Apex Angles.

1. Introduction

Fluidized beds represented an environmentally acceptable way of exploiting Indian. Coal reserves, prompting an increase in research and development related to fluidized-bed coal gasification and combustion. Although the underlying interest in fluidized beds is primarily related to their environmental performance, the hydrodynamics of a fluidized bed significantly influences both its environmental and thermal performance. Hence, understanding the hydrodynamics of fluidized beds is essential to fully capitalize on the benefits of fluidized bed combustion/gasification.

Pressurized fluidized bed gasifier (PFBG) represents a new technology that offers higher cycle efficiencies than traditional atmospheric-fluidized-bed and pulverized-coal combustor. This study focuses on the hydrodynamics of PFBG that provides the added potential for operating in a combined-cycle configuration. IGCC is an emerging technology with potential for great impact on electric power generation. With the introduction of PFBG plant the overall efficiency of the power plant increases to 40-45% compared to 30-35% of conventional power plants. Therefore the importance has been given to the study of fluidization phenomenon. In Pressurized Fluidized Bed Gasifier (PFBG) during gasification of low grade coal, the elutriation of unburnt carbon with fly ash is observed to be about 10-16% bringing down the carbon conversion efficiency. The reason for the same is attributed to bubble coalescence and breaking of large bubbles at the surface (splash zone) throwing out fines along with unburnt carbon at higher than the terminal velocity of particles as reported by Davidson. J.F,etal 1971while using conventional flat plate or conical type of distributors The elutriation is further expected to increase with increase in gasifier operating pressure. One of the objective of this work is to investigate the influence of distributor types on the performance of fluidized bed reactors using group B particles as per Geldart D,.1972. Classification, with most particles of size 40 μm < d_p< 500 μm and density 1.4 < ρ_s < 4 gm / cm^3 covering bubbling regime. .

To properly design a fluidized bed gasifier there is a particular need to develop laboratory scale beds operating at standard conditions that will properly simulate the hydrodynamics of a commercial unit operating at elevated pressure and temperature. It is more efficient to conduct controlled experiments in smaller cold model beds and compare confidently the test results to larger scale beds at actual operating conditions. Experiments can then be carried out in beds where detailed measurements of bed behavior can be made and modifications are simpler and less expensive. Also material problems due to harsh environments with in the bed will be avoided.

A set of scaling laws were systematically developed that allow a bed operating at ambient conditions to model the hydrodynamic conditions of a bed at elevated pressure and temperature. In the full set of scaling laws both hot bed and cold model must be geometrically similar and the diameter is arrived. In this case Reynolds number, the Froude number, the ratio of particle to fluid density, the dimensionless and particle size distribution is maintained same.

2. Cold Model Studies:

On the basis of full scaling parameters, the cold model reactor has dimensions that are too smaller than those of the hot gasifier. Hence, it is desirable to identify a reduced set of scaling relationships that permits a scale factor to be supplied as a free parameter rather than determined by the scaling parameters themselves. Glicksman et al (1984, 1986) also proposed a simplification to the full set of scaling parameters, which allow the scale factor for the bed dimension to be chosen independently. The simplification is based on the reduction on the number of dimensionless groups when either viscous or inertial effects dominate the fluid particle drag. In both viscous and inertial limits the scaling parameters reduce to groups listed below are referred as the simplified set of scaling parameters.

$d_p^3\rho_g (\rho_p-\rho_g)g/ \mu_g^2$, ρ_g / ρ_s, U_o^2/gD , U_o/U_{mf}, L/D , $Ø_s$, PSD.

where $Ø_s$ and PSD are included to match U_{mf} between two fluidized beds. A perspex three dimensional semi circular test rig reactor of ID 940mm hydrodynamically scale down model of a demonstration size 168 tpd PFBG plant is constructed as shown schematically in Fig.1. The cold model of fluidized bed reactors is discussed at M.T. Nicastro and .R.Glicksman (1984), Jochim Werther (1992), R.DiFelice,S.Rapagna, P.U.Foscolo and L.G.Gibilaro (1992) and Peter E.G.Gogolek and John R.Grace(1995).

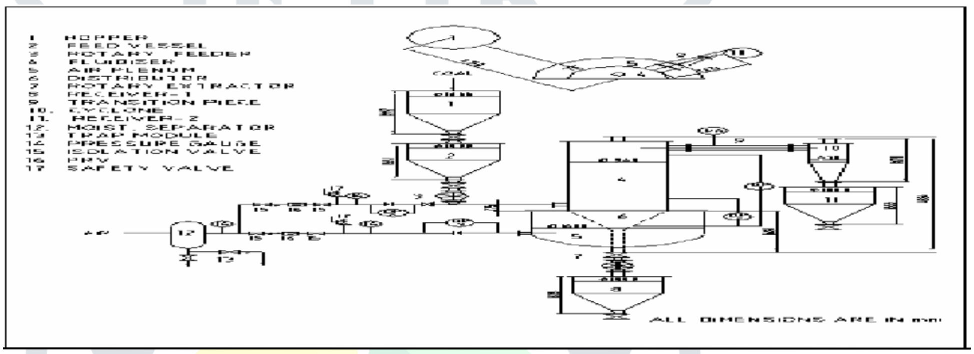


Fig.1. Schematic drawing of 940 mm dia Semi Circular Test Rig

The simplified scaling relations are used to arrive at the particle density in cold model conditions. The simplified scaling parameters of 168 TPD-PFBG hot and cold model is given at table.1. It is found that Iso - propylene material with a density of 925 kg/m^3 for cold model tests is hydro dynamically similar to bed ash material used in hot model test rig. The scale factor of two thirds is chosen and accordingly the bed diameter, expanded bed height and other hydrodynamic parameters have been fixed for the cold model test rig. A comparison of hydrodynamic parameters of 168 TPD PFBG hot and cold model is given at table 2.

The experimental study is carried out on 940 mm ID semi circular cold model (hydro dynamically scaled down model of 168 TPD-PFBG).This experimental work presents the influence of varying apex angle of the conical distributor on the hydrodynamic behavior of fluidized bed covering bubbling regime. The expanded bed height and bubble size were measured for each of the test conditions. The bed void age is used as the parameter for indicating the fluidization quality in selecting the final configuration of the distributor.

3. Description of Experimental Set up:

A Perspex three dimensional 940 mm dia semi circular test rig reactor hydro dynamically scale down model of 168 TPD – PFBG plant is shown schematically at Fig.1. The photographs of Semi circular test rig and control valves are given at figures 3 & 4. The scaling relations are used to arrive at the particle density. The scale factor (m) of two thirds is chosen and accordingly the bed diameter was fixed for the test rig. The conical distributers of apex angle 60^0 and 120^0 have been used and hydrodynamically investigated.

4. **Conical Distributor**:

Many types of distributors have been developed to improve the gas distribution in a fluidized bed. The choice of distributor is governed by the process and the operating conditions. The multi-orifice plate is the simpliest gas distributor used in industries. Its ease of construction and maintenance makes it a common choice. Further the bubble-cap type of orifice has been specially designed to prevent the back-flow of solids through the distributor. In a fluidized bed the distributor plate must be designed to offer uniform fluidization through the bed cross section. Uniform fluidization is achieved only if the distributor plate imposes a resistance to the total flow sufficient to over-come the fluids inherent resistance to rearranging and redistributing itself. Hence for proceeding with design and sizing of a distributor, the pressure drop across the distributor has to be assumed. The usual practice is to assume the distributor loss as a fraction of the bed pressure loss. Many investigations show that a ratio of distributor loss to bed pressure loss of about 0.3 to 0.4 has been recommended. The conical distributor is shown in Fig 2 and is provided with 10 rows, each row consisting of 16 equispaced holes of diameter 5.7mm arranged in a zigzag manner at a pitch of 40mm between each row.

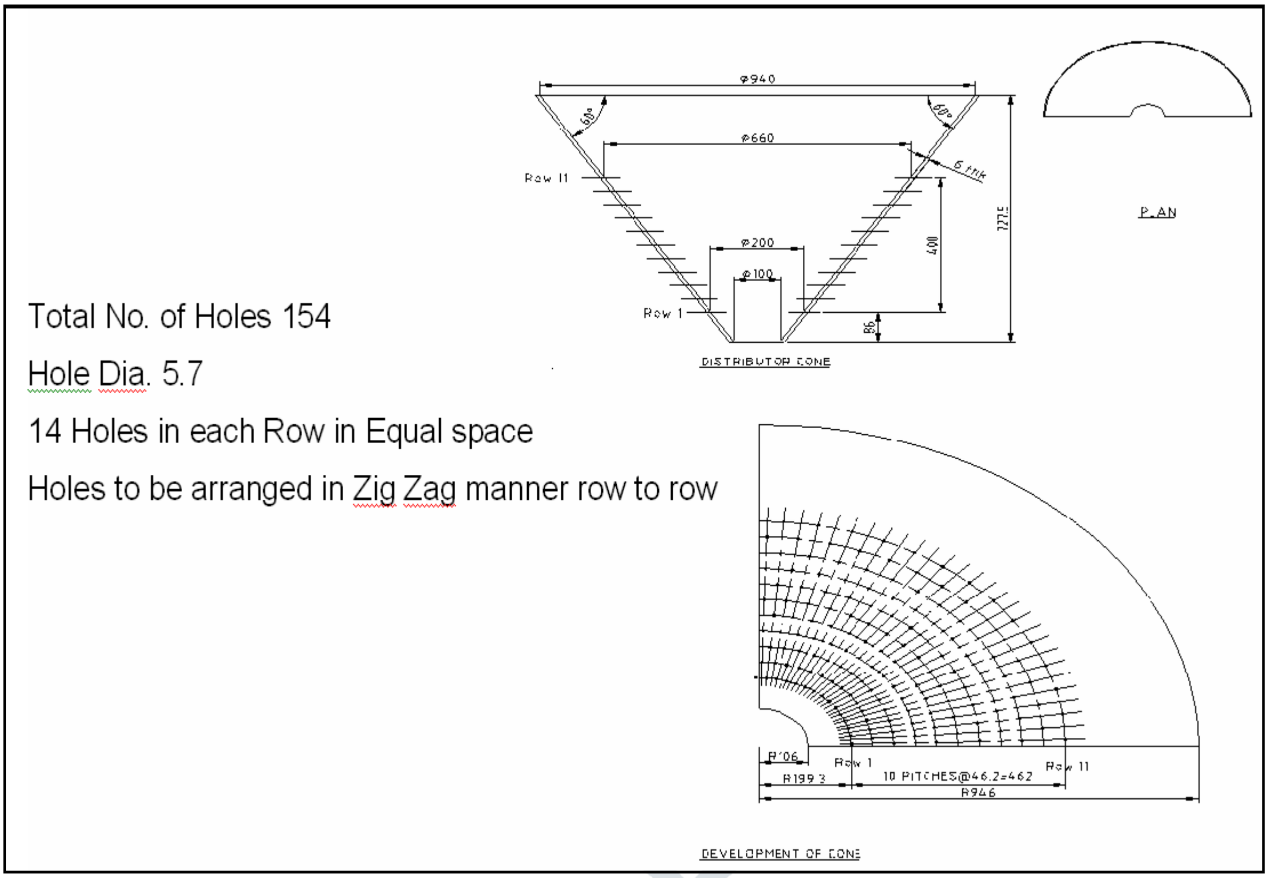


Fig. 2 Conical Distributor of Semi circular Test Rig

Fig.3. Photograph of Semi Circular Cold Model Test Rig

Fig.4. Photograph of control valves of Semi Circular Cold Model Test

5. COLD MODEL INSTRUMENTATION

5.1 Cold Model Pressure Measurement

The cold model is instrumented to measure the pressure drop between all the successive pressure taps. The cold model data was collected using a four, fast-response pressure transmitters which were calibrated with water manometers to the ranges 0f (0-2000mmWC), (0-600mmWC), (0-500mmWC), (0-1000mmWC). The data for each level in the cold model were taken. TATA-HONEY WELL CO. (series 600) made the pressure transducers.

5.2 Cold Model Data Acquisition System

The time-varying pressure drop measurements from the cold model were sampled using a personal computer-based Data Acquisition System (DAS). A computer equipped with EXPERT MODULE I/O card and data acquisition software developed in VC^{++} were used to sample the pressure transducer signal. The EXPERT MODULE I/O card was connected to pressure transducers through RS- 485 serial communication across which 24V DC supply was supplied. The EXPERT MODULE I/O card is a high-speed 12-bit analog-to-digital converter that can accommodate up to 8 single ended inputs and outputs.

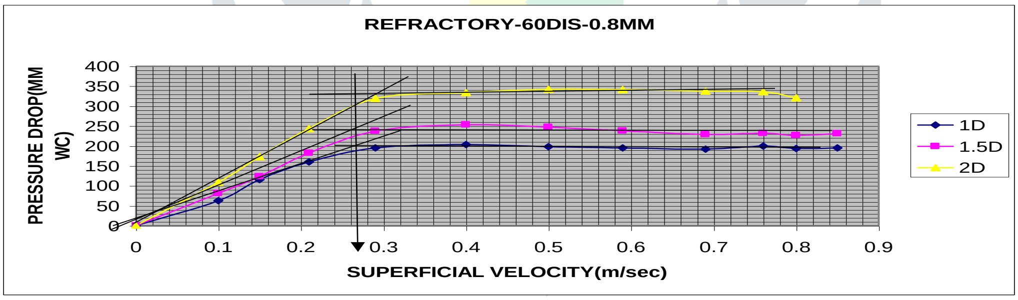
5.3 Cold Model Air Flow Measurement:

The air flow rate through the cold model was measured using a concentric-bore orifice Plate. The orifice plate was made of 304 stainless steel and had a bore of 13.9mm, giving it a diameter ratio ($\beta_{orifice} = d_{orifice} / D_{pipe}$) of 0.5217.The orifice plate was installed between a pair of orifice flanges that were equipped with pressure taps for measuring the pressure drop across the orifice plate. The orifice pressure drop was measured using a pressure transmitter. As recommended by the manufacturer, the orifice plate was installed with a minimum of 10 pipe diameters of straight pipe upstream of the plate and 5 pipe diameters of straight pipe downstream from the orifice plate. The air flow rate was calculated using measurements of the orifice pressure-drop, the temperature of the air in the line, and the gage pressure in the line.

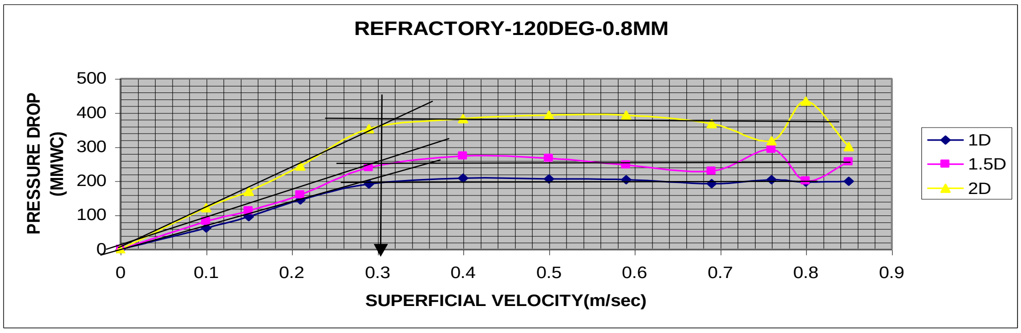
6. Results and Discussion

At first, the distributor pressure drop of each distributor with respect to empty fluidizer has been noted down at respective superficial velocities, at which the pressure drops of solids filled fluidizer are noted. These distributor pressure drop (ΔP_d) values were subtracted from overall pressure drop ($\Delta P_{overall}$) values at respective velocities to get the bed pressure drop (ΔP_{bed}) values at the same velocities. These ($\Delta P_{d, w.s}$), ($\Delta P_{overall}$), (ΔP_{bed}) values were given in the following tables. The ΔP_{bed} values obtained were used to draw the graph between bed pressure drop (ΔP_{bed}) and superficial velocity (U_o).

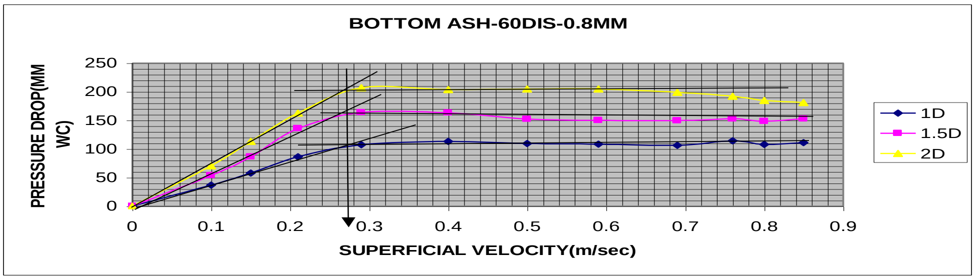
The experimental data has been recorded by doing experiments with material REFRACTORY of mean particle size- 0.8 mm at different bed heights (1D, 1.5D, 2D) using distributors with apex angles such as 60^0 and 120^0. The data is then used to find minimum fluidization velocity (U_{mf}) values at respective bed heights for each of two distributors with apex angles such as 60^0 and 120^0, as shown in graphs.1 & 2 respectively. In the same way, the experimental data has been recorded by conducting experiments with material BOTTOM ASH of mean particle size - 0.8 mm at different bed heights (1D, 1.5D, 2D) using two distributors with apex angles such as 60^0 and 120^0. The experimental data is then used to find minimum fluidization velocity (U_{mf}) values at respective bed heights for each of two distributors with apex angles such as 60^0 and 120^0, as shown in Graph.3 & 4 respectively.



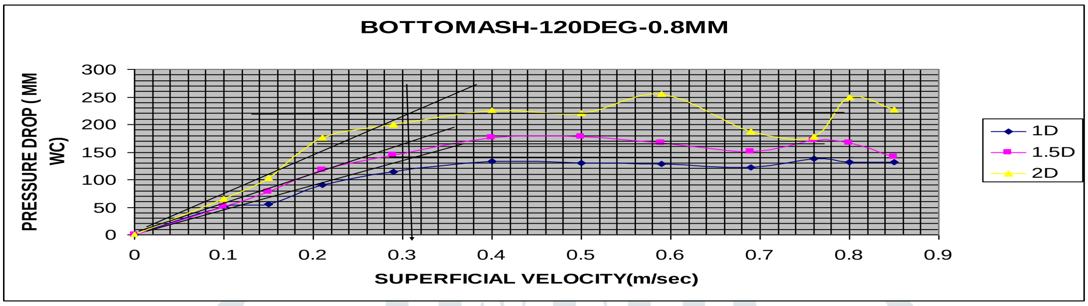
GRAPH 1 REFRACTORY – 60^0 - 0.8mm



GRAPH 2 REFRACTORY – 120^0 - 0.8mm



GRAPH 3 BOTTOMASH – 60^0 - 0.8mm



GRAPH 4 BOTTOMASH -120^0 - 0.8mm

Table 1: Simplified Scaling Parameter Comparison of 168 TPD-PFBG and Cold Model

PARAMETERS	168 TPD HOT BED	COLD MODEL(2/3 SCALE)
ρ_s / ρ_g	750	750
U^2/gDo	0.051	0.051
U_o/ U_{mf}	2.96	2.96
ϕ_s	0.63	0.65
Drig / dp	1420	1420

Table 2: Comparison Of 168TPD HOT PFBG plant and Cold Model Parameters

PARAMETERS	168 TPD HOT BED	COLD BED (2/3rd SCALE) SEMI-CIRCULAR
Temperature(K)	1273	303
Pressure(atm)	13	1
Gas Density(kg/m^3) ρ_g	3.26	1.2
Solid Density(kg/m^3) ρ_s	2248	900
Air Flow in Distributor(kg/hr)	12733	1025
Minimum Fluidization Velocity(m/s)U_{mf}	0.2256	0.231
Operating Velocity(m/s)U_o	0.843	0.683
Diameter of Bed(m)	1.4	0.94
Particle Diameter(mm)	0.986	0.662
Orifice Diameter (mm)	5.7	5.7
Number of orifices in distributor N	370	154
Orifice velocity (m/s) U_{or}	38.6	54
Pressure Drop in bed (kg/m^2)ΔP_b	2898	795
Pressure Drop in distributor (kg/m^2)ΔP_d	1159	318
Static bed height(m) H_{static}	1.745	1.203
Expanded bed height (m) H_f	2.473	1.660

7. Conclusions

The following conclusions are drawn from the experimentation on semi-circular test rig which is scale down model of 168 TPD PFBG that the mechanism of fluidization is dependent on distributor apex angle, particle density, and static bed height. The bed height remains constant as the airflow is increased from zero to minimum fluidization because bed was packed. After fluidization bed height was found to increase rapidly with increasing gas superficial velocity. And the expanded bed heights were found to be less when airflow is decreasing than airflow is increasing from zero to maximum.

The measured hydrodynamic parameters of conical distributors plotted graphically viz., superficial velocity versus pressure drop. It is observed that the pressure drop values were found to be decreasing with increasing distributor apex angles from 60^0 to 120^0.

Nomenclature

A_R	Reactor area	(m^2)
A_{or}	orifice area	(m^2)
A_s	Surface area	(m^2)
Ar	Archimedis number,	$d_p^3\rho_g(\rho_p-\rho_g)g/\mu_g^2$
C_d	Co-efficient of discharge for gas issuing from an orifice	
C_{pw}	Specific heat of water at constant pressure	(kj/kg k)
C_{ps}	Specific heat of steam at constant pressure	(kj/kg k)
D	Reactor Diameter	(m)
D_b	Bubble Diameter	(m)
d_{or}	Orifice Diameter	(m)
$\overline{D_p}$	Mean particle diameter	(m)
D_{b0}	Initial Bubble size	(m)
ε_{static}	Voidage of static bed	
ε_{mf}	Voidage of bed at minimum fluidization condition	
Fr	Frode number	
G	Mass flow	(kg/hr)
g	Acceleration due to gravity	(m/s^2)
H	Bed Height	(m)
H_J	Jet penetration	(m)
H_S	Static bed height	(m)
H_{mf}	Height of the bed at minimum fluidization	(m)
H_f	Height of Fluidized bed	(m)
K	constant	
m_s	Mass of steam	(kg/hr)
m_a	Mass of air	(kg/hr)
M	Molecular weight,	(Kg)
N_{or}	Number of orifices	
P	Pressure	(kg/cm^2)
ΔP_b	Bed pressure drop	(kg/m^2)
ΔP_d	Distributor pressure drop	(kg/m^2)
ΔP_t	Total bed pressure drop	(kg/m^2)
Re_{mf}	Reynolds number at minimum fluidization condition	
Re_{dp}	Particle Reynolds number	
T	Temperature	(^0C)
U_b	Bubble velocity	(m/sec)
U_o	Superficial Gas velocity (Operating Velocity)	(m/sec)
U_{or}	Orifice Velocity	(m/sec)
U_{mf}	Minimum Fluidization Velocity	(m/sec)
U_t	Terminal Velocity	(m/sec)
V_D	Distributor Volume	(m^3)

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