SCIREA Journal of Information Science
and Systems Science
ISSN: 2995-3936
http://www.scirea.org/journal/ISSS
March 11, 2025
Volume 9, Issue 1, February 2025
https://doi.org/10.54647/isss120387

A Critique By

Hubert M Quinn, The Wrangler Group LLC, 40 Nottinghill Road, Brighton, Ma. 02135

To the thesis entitled “PRESSURE DROP IN A PEBBLE BED REACTOR” Published in Calendar year 2010 By CHANGWOO KANG

Hubert M Quinn

The Wrangler Group LLC, 40 Nottinghill Road, Brighton, Ma. 02135,United States

Introduction

The thesis to which this critique is directed, was published in the calendar year 2010. It was,

“Submitted to the Office of Graduate Studies of Texas A&M University in partial fulfillment of the requirements for the degree of master of Science”

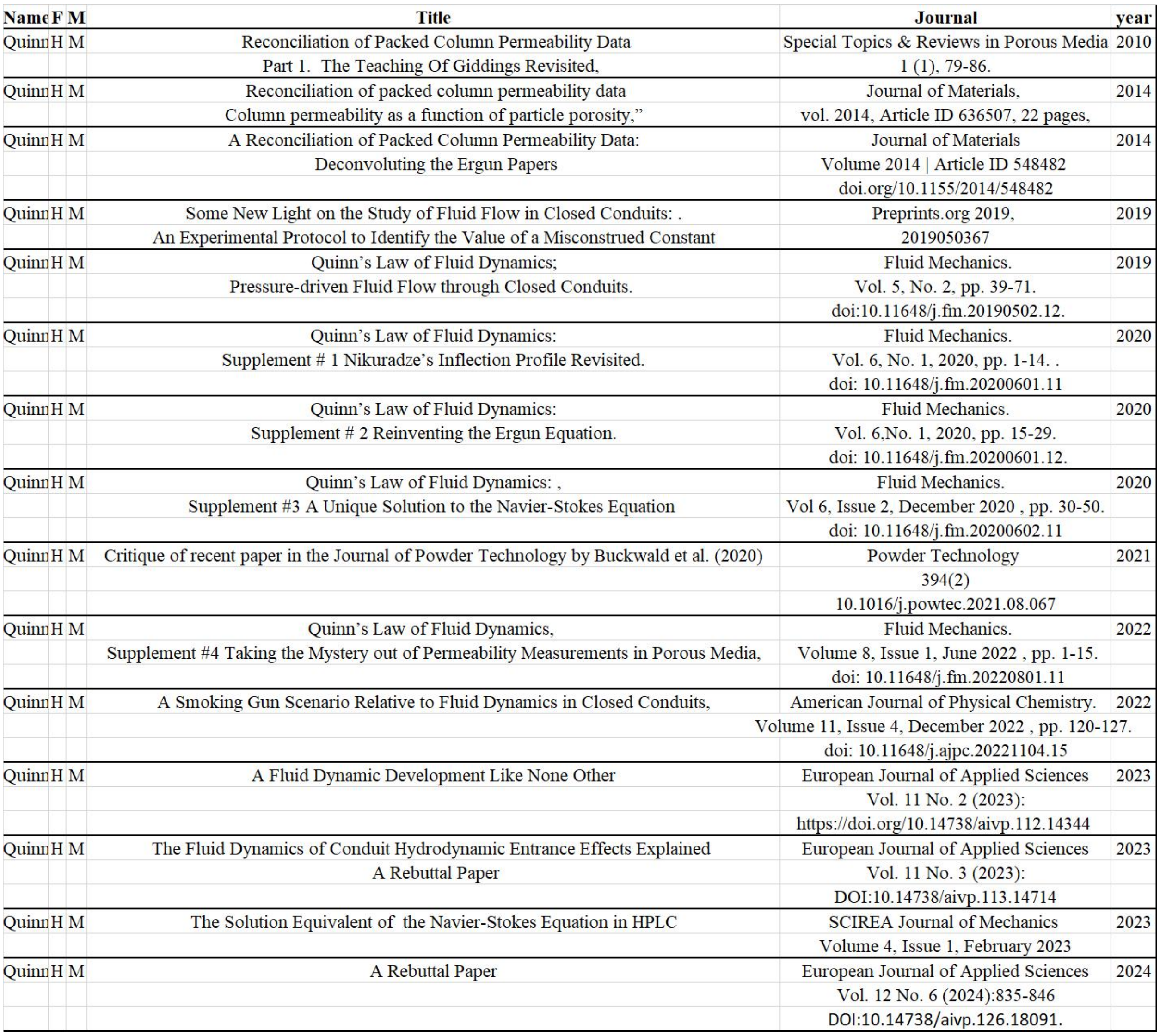
I am a career scientist who has devoted his entire professional career to fluid flow in closed conduits. I submit this critique as a constructive way to promote my concepts *vis a vis* the conventional wisdom.

The QFFM

The abbreviation, QFFM, stands for the **Q**uinn **F**luid **F**low **M**odel, which is a comprehensive novel theory of fluid flow in closed conduits. It was published in the year 2019. It supersedes all extant fluid flow models on this subject matter, on the basis of experimental verification applicable to both empty and packed conduits, see Table 1A below.

In this analysis, I will demonstrate that the QFFM is the more appropriate methodology in which to view the measured data contained in this very thorough study of fluid flow in closed conduits.

Table 1A



Name	F	M	Title	Journal	year
Quinn	H	M	Reconciliation of Packed Column Permeability Data	Special Topics & Reviews in Porous Media	2010
			Part 1. The Teaching Of Giddings Revisited,	1 (1), 79-86.	
Quinn	H	M	Reconciliation of packed column permeability data	Journal of Materials,	2014
			Column permeability as a function of particle porosity,"	vol. 2014, Article ID 636507, 22 pages,	
Quinn	H	M	A Reconciliation of Packed Column Permeability Data:	Journal of Materials	2014
			Deconvoluting the Ergun Papers	Volume 2014 | Article ID 548482	
				doi.org/10.1155/2014/548482	
Quinn	H	M	Some New Light on the Study of Fluid Flow in Closed Conduits: .	Preprints.org 2019,	2019
			An Experimental Protocol to Identify the Value of a Misconstrued Constant	2019050367	
Quinn	H	M	Quinn's Law of Fluid Dynamics;	Fluid Mechanics.	2019
			Pressure-driven Fluid Flow through Closed Conduits.	Vol. 5, No. 2, pp. 39-71.	
				doi:10.11648/j.fm.20190502.12.	
Quinn	H	M	Quinn's Law of Fluid Dynamics:	Fluid Mechanics.	2020
			Supplement # 1 Nikuradze's Inflection Profile Revisited.	Vol. 6, No. 1, 2020, pp. 1-14. .	
				doi: 10.11648/j.fm.20200601.11	
Quinn	H	M	Quinn's Law of Fluid Dynamics:	Fluid Mechanics.	2020
			Supplement # 2 Reinventing the Ergun Equation.	Vol. 6,No. 1, 2020, pp. 15-29.	
				doi: 10.11648/j.fm.20200601.12.	
Quinn	H	M	Quinn's Law of Fluid Dynamics: ,	Fluid Mechanics.	2020
			Supplement #3 A Unique Solution to the Navier-Stokes Equation	Vol 6, Issue 2, December 2020 , pp. 30-50.	
				doi: 10.11648/j.fm.20200602.11	
Quinn	H	M	Critique of recent paper in the Journal of Powder Technology by Buckwald et al. (2020)	Powder Technology	2021
				394(2)	
				10.1016/j.powtec.2021.08.067	
Quinn	H	M	Quinn's Law of Fluid Dynamics,	Fluid Mechanics.	2022
			Supplement #4 Taking the Mystery out of Permeability Measurements in Porous Media,	Volume 8, Issue 1, June 2022 , pp. 1-15.	
				doi: 10.11648/j.fm.20220801.11	
Quinn	H	M	A Smoking Gun Scenario Relative to Fluid Dynamics in Closed Conduits,	American Journal of Physical Chemistry.	2022
				Volume 11, Issue 4, December 2022 , pp. 120-127.	
				doi: 10.11648/j.ajpc.20221104.15	
Quinn	H	M	A Fluid Dynamic Development Like None Other	European Journal of Applied Sciences	2023
				Vol. 11 No. 2 (2023):	
				https://doi.org/10.14738/aivp.112.14344	
Quinn	H	M	The Fluid Dynamics of Conduit Hydrodynamic Entrance Effects Explained	European Journal of Applied Sciences	2023
			A Rebuttal Paper	Vol. 11 No. 3 (2023):	
				DOI:10.14738/aivp.113.14714	
Quinn	H	M	The Solution Equivalent of the Navier-Stokes Equation in HPLC	SCIREA Journal of Mechanics	2023
				Volume 4, Issue 1, February 2023	
Quinn	H	M	A Rebuttal Paper	European Journal of Applied Sciences	2024
				Vol. 12 No. 6 (2024):835-846	
				DOI:10.14738/aivp.126.18091.	

Methodology

In evaluating any paper, I accept as valid, all measurements of flow rate and pressure drop. This is a reasonable conclusion since it is broadly accepted that volumetric flowmeters and pressure transducers are highly accurate. On the other hand, the measurements of particle diameter and packed column external porosity are universally regarded as fraught with problems. I then use the teaching of the QFFM to back-calculate the values for the average spherical particle diameter equivalent, d_p, as well as the packed column external porosity, e_0. The QFFM is the only model capable of doing this because it contains all the variables in the pressure flow relationship in closed conduits, including a parameter which quantifies the so-called wall-effect.

Permeability

I typically begin by showing the correlation achieved when using this methodology between the measured data reported in the paper and the calculated data based upon the QFFM. I present the QFFM calculated results here in the form of a permeability plot for each dataset, displayed in Fig 1A-1, Fig 1A-2 and Fig 1B.

Fig. 1A-1

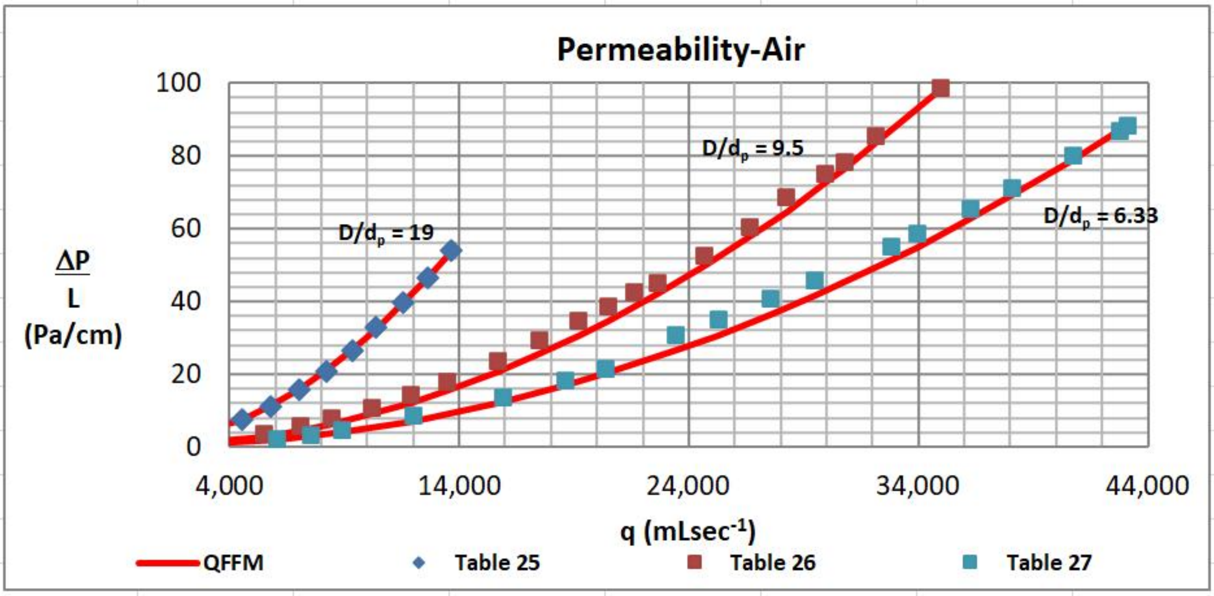


Fig. 1A-2

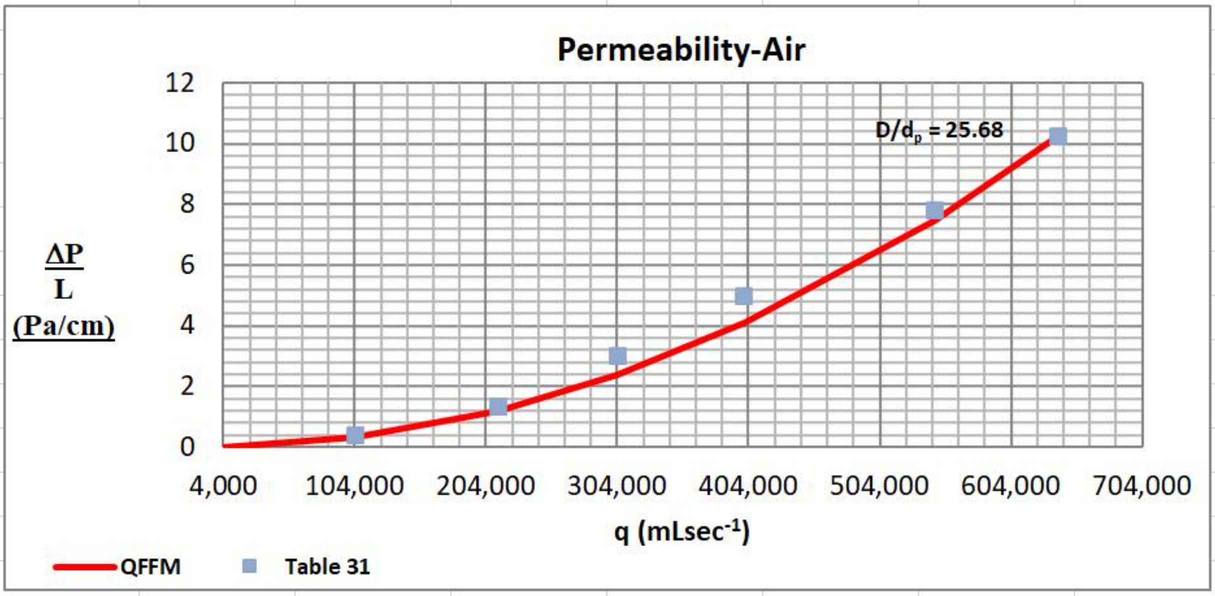
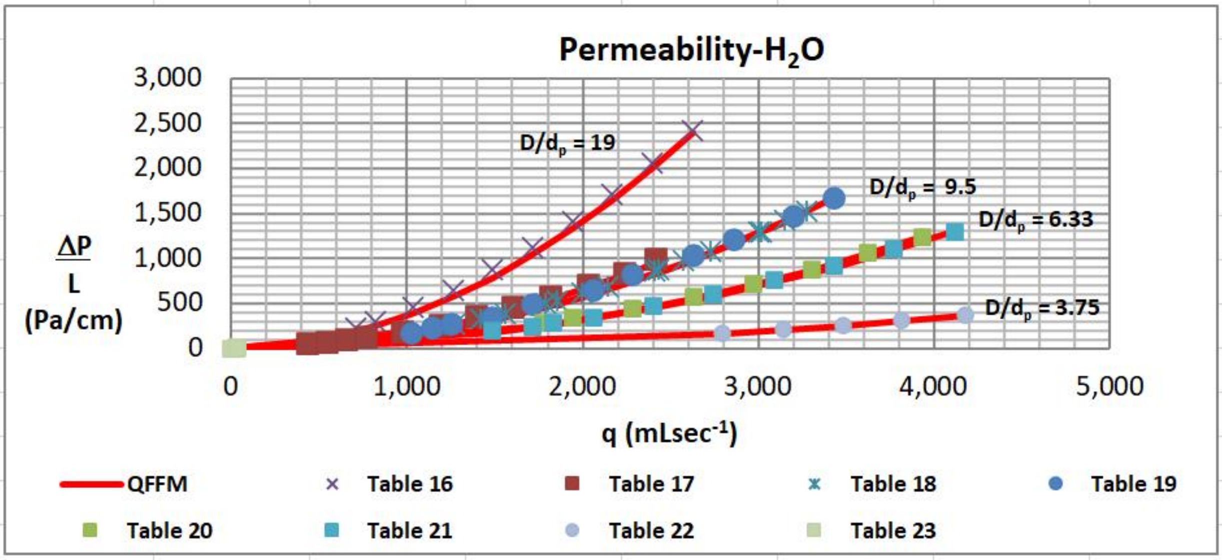


Fig 1B



As can be seen from the plots, I have included all datasets, representing the information reported. I have used the pressure gradient on the y-axis (DP/L) in order to normalize for conduit length L. Note that there is, virtually, a perfect correlation between the data reported in the paper for each of the reported datasets and the QFFM calculated data.

This plot, then, represents my *bona fides* with respect to my analysis of this study which is totally driven by the accurately measured data of volumetric flow rate and differential pressure, reported in the many Tables of the thesis.

Hydraulic Gradient

The QFFM methodology is based upon the Forchheimer model which balances the measured and calculated data using a quadratic relationship between hydraulic gradient, i = [DP/(r_fgL)] and fluid superficial velocity m_s = [4q/(pD^2)], where q is the measured fluid volumetric flow rate, DP is the measured pressure differential, D and L are the measured dimensions of the empty conduit and g is the acceleration due to gravity. The linear and quadratic coefficients of the 2nd order polynomial of this relationship, a and b, respectively, also referred to typically as "Forchheimer Coefficients" are in reality, "fudge factors", which guarantee a perfect fit between the measured and modelled data. The hydraulic gradient is calculated based upon two additional universal variables which are the fluid density, r_f, and the acceleration due to gravity, g. Therefore, the Forchheimer model does not depend on either the value of the particle diameter d_p or the external porosity of the packed column e_0 but incorporates two additional "pegs in the ground" not found in any of the fluid models which pertain to the linear (laminar) flow regime.

Fig. 2A-1

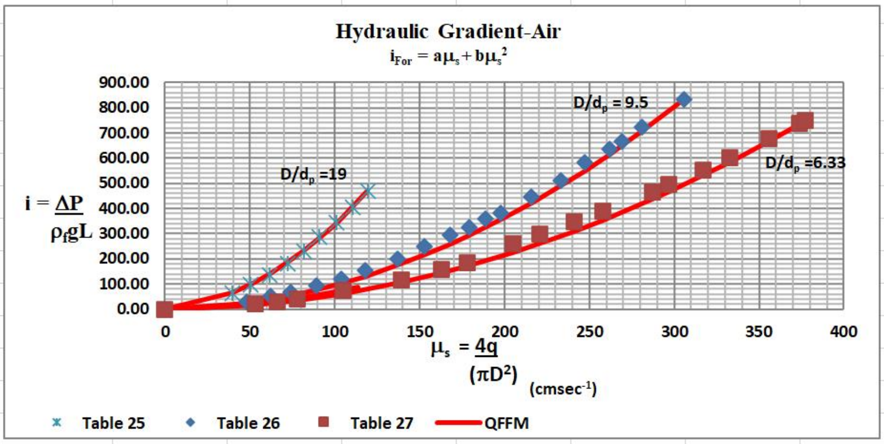


Fig. 2A-2

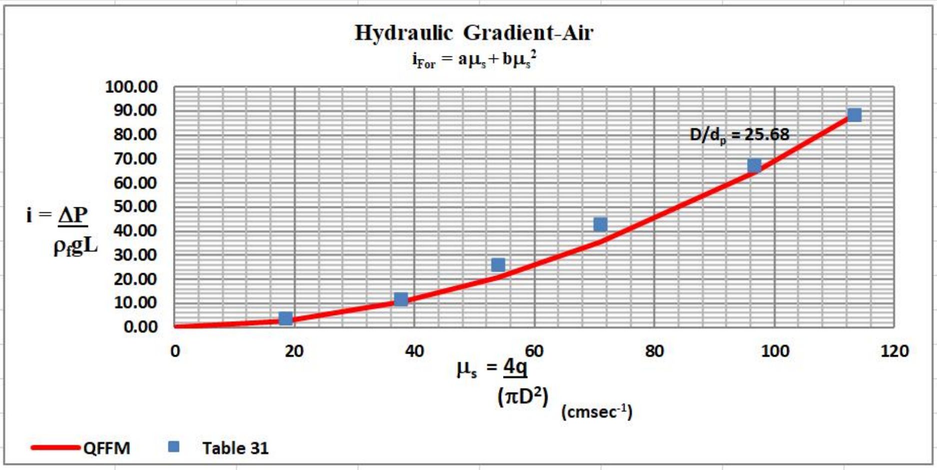
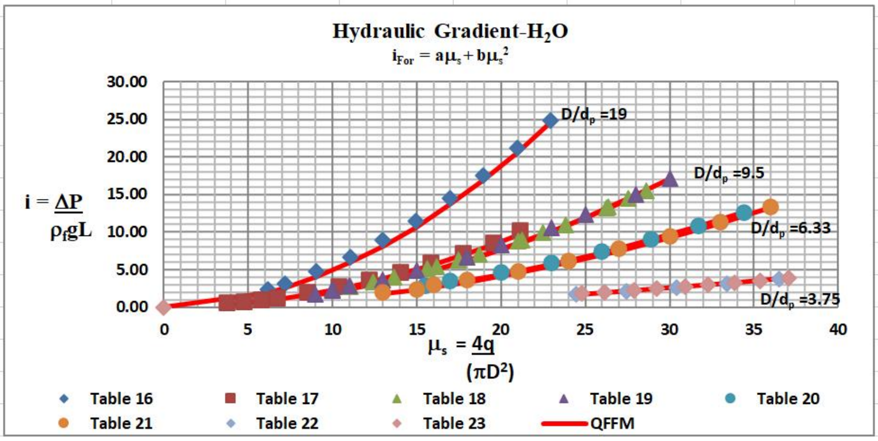


Fig. 2B



We point out that, in Hydraulic Gradient plots, both axes are normalized, the y-axis for L and x-axis for D. Note that the shape of the lines appears to be slightly curved suggesting that measurements of flow rate and differential pressure are taken in the transitional/turbulent region of the fluid flow regime. When measurements are taken at higher and higher values of the modified Reynolds number, however, these lines become increasingly more curved in shape.

Viscous type friction factor f_V - The Q- Modified Ergun Model

Fig. 3A-1

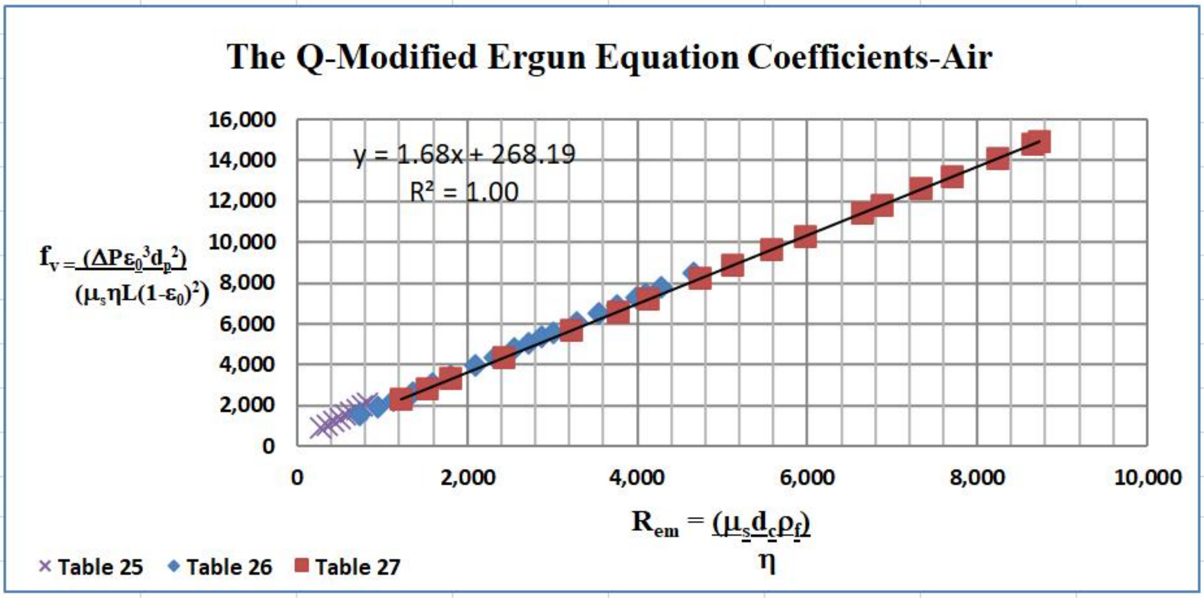


Fig. 3A-2

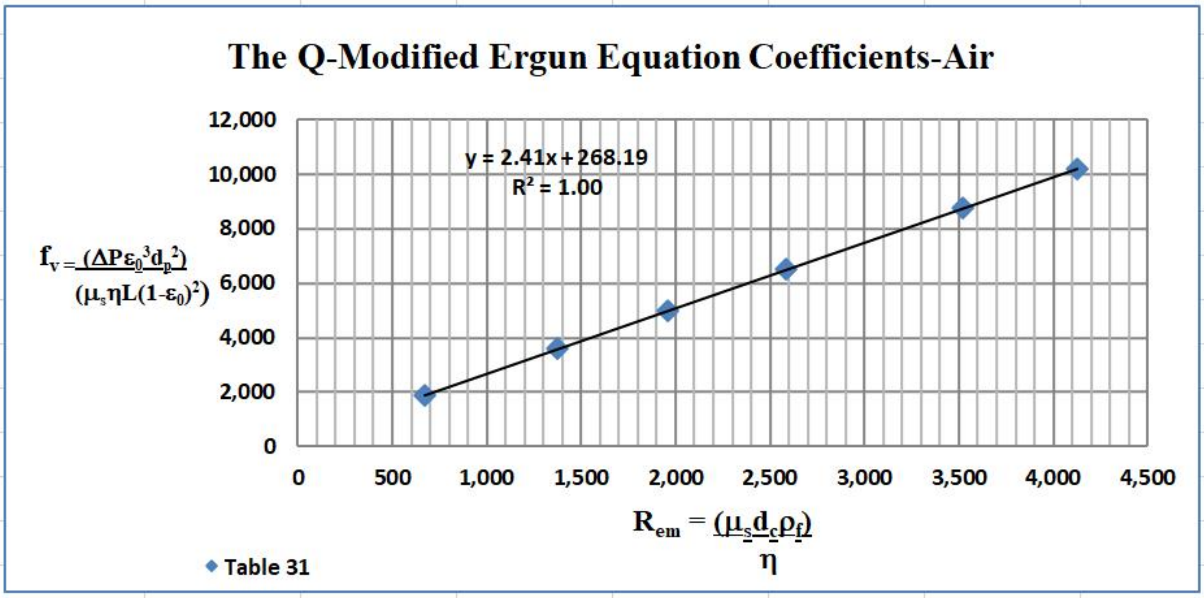
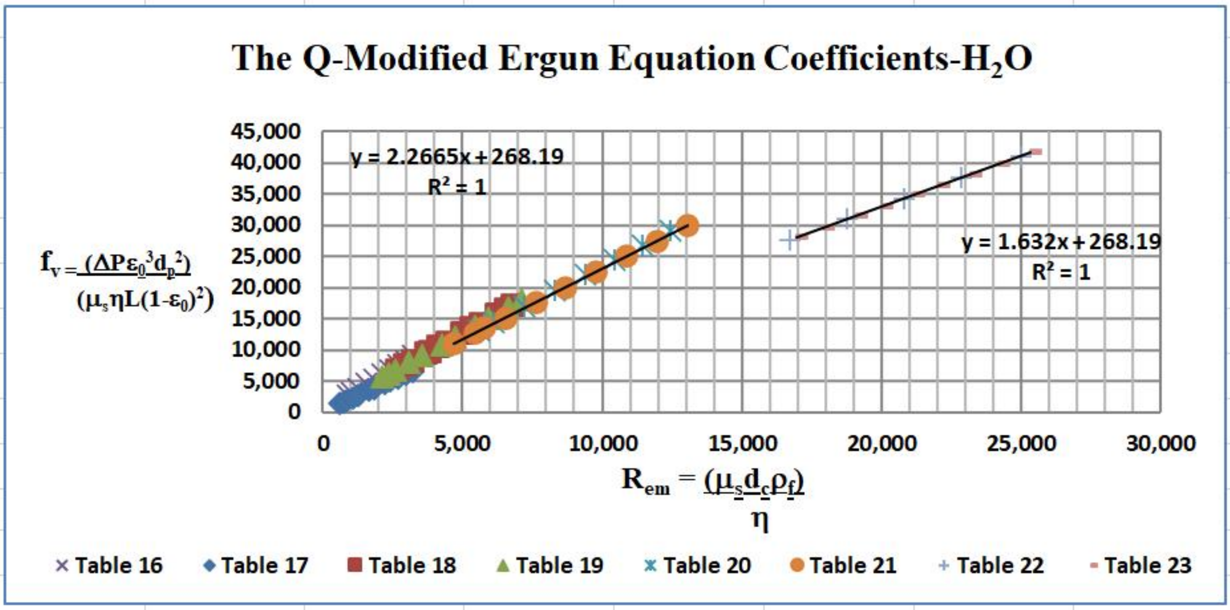


Fig. 3B

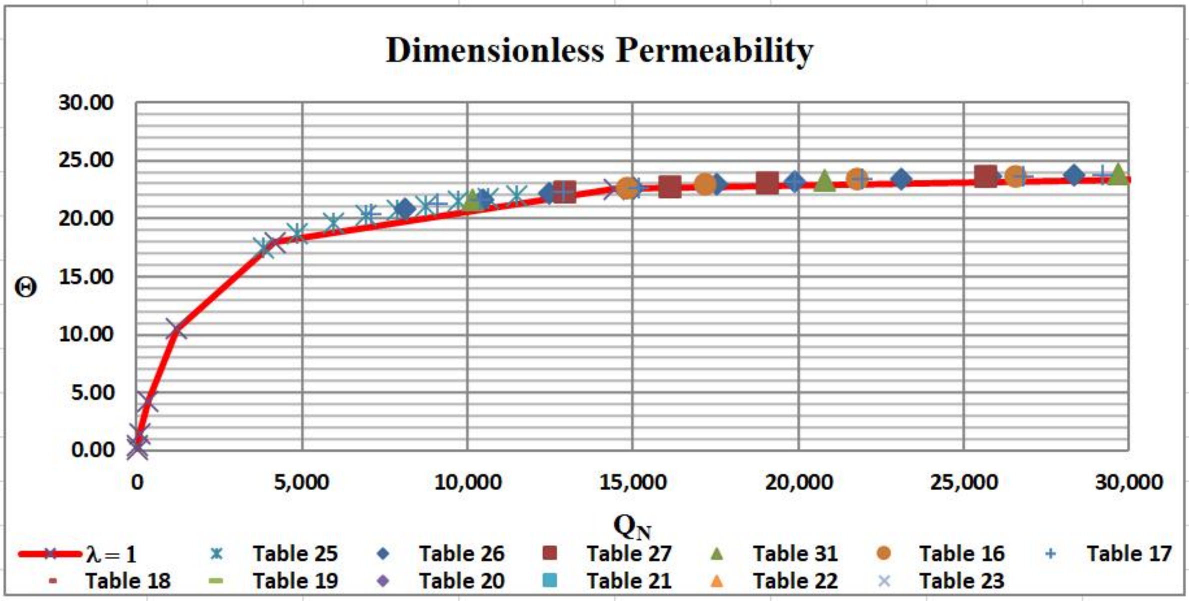


As shown in these plots, we display the datasets as a viscous type friction factor, f_v, versus the modified Reynolds number R_{em}. The parameter $f_v = DPe_0^3 d_p^2/(m_s hL(1-e_0)^2$, were h is the absolute fluid viscosity. The parameter $R_{em} = m_s d_p\ r_f/[(1-e_0)h]$ and the relationship shown in Fig 3A was originally taught by Ergun circa 1951 and it enables the calculation of the Ergun coefficients A and B as the intercept and slope of the plotted lines. In the plots herein, of course, the values of A and B represent the coefficients of the **Q-modified** Ergun model which means that the original Ergun model is modified according to the teaching of the QFFM. Note that in the Q-modified model, the value of A is always a constant = 268.19, but the value of B is not constant and, rather, is defined by the relationship $B = [l/(2pe_0^3)]$, where l = the wall normalization coefficient. These values are in contrast to the original Ergun model values of 150 and 1.75 for the values of A and B, respectively. Note also, that the QFFM teaching is unique amongst all extant models, in as much as it has a built-in methodology to account for "wall-effect" via its parameter l, which is independently defined on the physics of the underlying fluid flow. This is in contrast to other models where the wall-effect is erroneously based entirely on the Reynolds number.

The Wall-Effect Impact Expressed as the value of l

As taught by the QFFM, the primary wall-effect is due to both the velocity and viscosity of the fluid in the close proximity to a confining wall and was identified as the viscous boundary layer by Prandtl circa 1930. In addition, a secondary wall-effect is due to the roughness of the particle surface. The parameter l in the QFFM quantifies the magnitude of the impact of both these wall-effects on the permeability of any packed or empty column. To isolate the impact of the value of l, therefore, the QFFM uniquely defines the Dimensionless Permeability parameter, Q, in a plot of Q versus Q_N, where $Q = 4Q_N/f_v$, and $Q_N = R_{em}/e_o^3$.

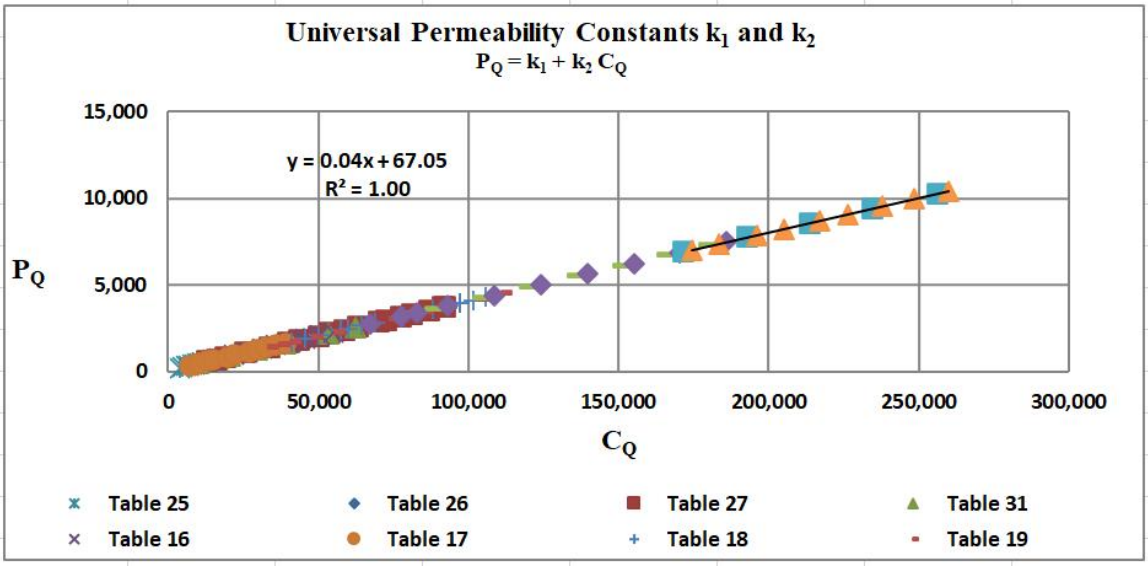
Fig 4A



Looking at Fig 4A, I note that a value of l = 1 represents that of a packed column which is free of all wall-effects. Note that all samples in this thesis fall on this line.

Quinn’s Law- A Universal relationship

Fig. 5A



In Fig 5A, I display the measured datasets on a plot of P_Q versus C_Q, which is now known as Quinn’s Law. The parameter $P_Q = (4f_v)$, and the parameter $C_Q = lQ_N$, the former represents the normalized pressure gradient also normalized for fluid drag: the latter represents the normalized fluid flow parameter including wall-effect also normalized for fluid drag. Note that all measured data fall on a unique straight line whose intercept and slope represent the values of k_1 and k_2 which are the universal constants in the pressure flow relationship in closed conduits.

Data Summary

In Table 1A, we display all relevant calculations based upon the teaching of the QFFM.

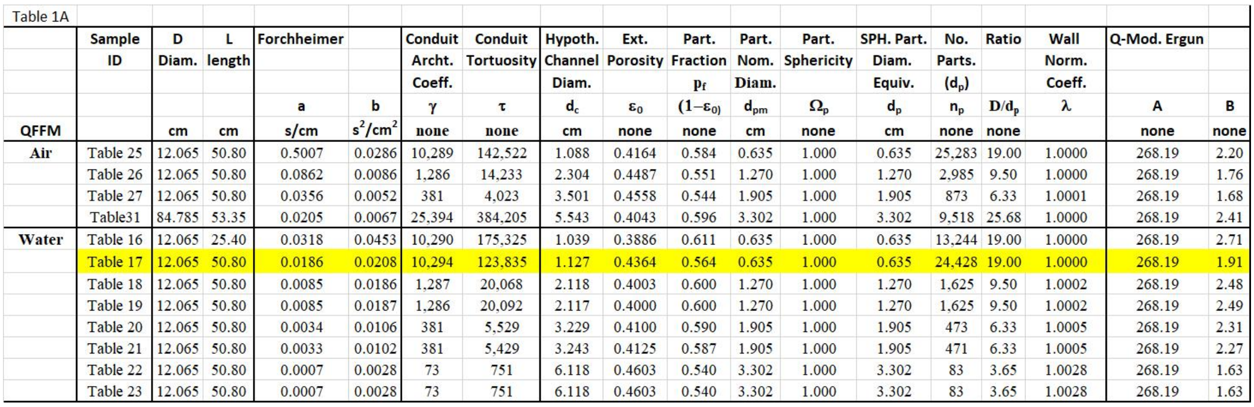


Table 1A

	Sample	D	L	Forchheimer		Conduit	Conduit	Hypoth.	Ext.	Part.	Part.	Part.	SPH. Part.	No.	Ratio	Wall	Q-Mod. Ergun	
	ID	Diam.	length			Archt.	Tortuosity	Channel	Porosity	Fraction	Nom.	Sphericity	Diam.	Parts.		Norm.		
						Coeff.		Diam.		p_f	Diam.		Equiv.	(d_p)		Coeff.		
				a	b	γ	τ	d_c	ε_0	$(1-\varepsilon_0)$	d_{pm}	Ω_p	d_p	n_p	D/d_p	λ	A	B
QFFM		cm	cm	s/cm	s^2/cm^2	none	none	cm	none	none	cm	none	cm	none	none		none	none
Air	Table 25	12.065	50.80	0.5007	0.0286	10,289	142,522	1.088	0.4164	0.584	0.635	1.000	0.635	25,283	19.00	1.0000	268.19	2.20
	Table 26	12.065	50.80	0.0862	0.0086	1,286	14,233	2.304	0.4487	0.551	1.270	1.000	1.270	2,985	9.50	1.0000	268.19	1.76
	Table 27	12.065	50.80	0.0356	0.0052	381	4,023	3.501	0.4558	0.544	1.905	1.000	1.905	873	6.33	1.0001	268.19	1.68
	Table31	84.785	53.35	0.0205	0.0067	25,394	384,205	5.543	0.4043	0.596	3.302	1.000	3.302	9,518	25.68	1.0000	268.19	2.41
Water	Table 16	12.065	25.40	0.0318	0.0453	10,290	175,325	1.039	0.3886	0.611	0.635	1.000	0.635	13,244	19.00	1.0000	268.19	2.71
	Table 17	12.065	50.80	0.0186	0.0208	10,294	123,835	1.127	0.4364	0.564	0.635	1.000	0.635	24,428	19.00	1.0000	268.19	1.91
	Table 18	12.065	50.80	0.0085	0.0186	1,287	20,068	2.118	0.4003	0.600	1.270	1.000	1.270	1,625	9.50	1.0002	268.19	2.48
	Table 19	12.065	50.80	0.0085	0.0187	1,286	20,092	2.117	0.4000	0.600	1.270	1.000	1.270	1,625	9.50	1.0002	268.19	2.49
	Table 20	12.065	50.80	0.0034	0.0106	381	5,529	3.229	0.4100	0.590	1.905	1.000	1.905	473	6.33	1.0005	268.19	2.31
	Table 21	12.065	50.80	0.0033	0.0102	381	5,429	3.243	0.4125	0.587	1.905	1.000	1.905	471	6.33	1.0005	268.19	2.27
	Table 22	12.065	50.80	0.0007	0.0028	73	751	6.118	0.4603	0.540	3.302	1.000	3.302	83	3.65	1.0028	268.19	1.63
	Table 23	12.065	50.80	0.0007	0.0028	73	751	6.118	0.4603	0.540	3.302	1.000	3.302	83	3.65	1.0028	268.19	1.63

Table 1A contains the relevant QFFM calculations the all 12 datasets.

Commentary

Firstly, note that because the particles are all spherical in this thesis, the particle sphericity, W_p, is 1.0

Secondly, note that the value of l is approximately 1.0 , hence no significant wall-effect in these samples. The value of l does, however, increase slightly as a function of the declining ratio of D/d_p. Since external porosity, e_0, is a function of both particle shape, W_p, and D/d_p ratio, it is not a wall-effect *per se*.

Conclusions

Based upon my analysis of the data presented in this thesis, I conclude as follows:

1. The measured data in this thesis validates completely the QFFM.
2. The measurements with air were taken at very low differential pressure (less than 1.0 psi) which results in more spread of the data comparison due to accuracy of the pressure measurements.
3. The measurements with H_2O were taken at higher differential pressure (up to 10 psi) and, accordingly, are more accurate, yielding smaller spread in the data comparisons.
4. The spread of the data comparisons is greater in both the air and water measurements at lower flow rates. This is, also, because of the greater experimental error at lower differential pressures.
5. Table 17 data is an outlier because the measurements were not taken at constant temperature and, therefore, each data point contained an additional measurement for fluid viscosity and density. This results in more spread in the data comparisons due to increased experimental error.
6. The QFFM provides a more comprehensive and accurate basis upon which to evaluate the data in this thesis than any of the other models, which were many, referenced in the text of the thesis.
7. The thesis, then, suggests that the QFFM is far more reliable than any other extant model, as of this writing.