



Particle Shape in Packed Conduits: A QFFM Comparative Analysis Part 1

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Abstract: In this paper the issue of changing particle shape in packed conduits containing solid particle is examined. In so doing, a recently published paper in which perforated spherical particles were compared to full spherical particles is chosen as the worked example. The paper under study is; Title; Flow and heat transfer in fixed beds of spherical catalyst supports with internal voids. Authors; Anthony G. Dixon, Behnam Partopour, Bhanu Vardhan Reddy Kuncharam. Journal; Chemical Engineering Journal 544 (2026) 178722.

In this paper under study, the authors made comparisons and drew conclusions which were based upon changing more than one variable at a time. Consequently, the QFFM, a relatively new fluid flow model, was used to make apples-to-apples comparisons together with corrected conclusions.

PROBLEM DEFINITION

In this paper under study, the authors conclude that perforated particles in packed conduits makes a difference in terms of the overall performance of the packed conduit, particularly, in the case of permeability and thermal characteristics. They use a theoretical model based on CFD, computational fluid dynamics, to compare the performance of conduits packed with solid spheres and spheres with holes (perforated spheres), suggesting, even further, that it is preferred to have the holes oriented perpendicular rather than parallel to the conduit walls. In reaching their conclusions, the authors embrace both the Reynolds number and the Ergun fluid models, presenting their results in plots of Ergun based friction factor versus the Reynolds number.

PROBLEM RESOLUTION

The methodology used and the conclusions reached by the original paper authors are found to be troublesome. Firstly, their conclusions are based upon an apples-to-oranges comparison of both categories of packed conduits, since they have created hypothetical packed conduits which are hydrodynamically different. Secondly, they adapt the conventional Reynolds number model as their governing equation of fluid motion in combination with the Ergun fluid model for packed conduit permeability, which constitutes a contradiction in terms. This is true since the Ergun model for packed conduits and the Reynolds number are mutually exclusive based upon the Reynolds number experiment of 1883 in which Sir Osborne Reynolds demonstrated that the TTP value (Turbulent Tipping Point) of the Reynolds number in an empty conduit falls in a range of 2100-2300.

Accordingly, in this paper, an alternative explanation for the reported data scenarios, using the QFFM (Quinn Fluid Flow Model), is provided, which renders significantly different conclusions than those expressed by the original paper authors.

APPLICATION OF THE QFFM

Table 1A-1

Apples-to-Oranges Comparison of Holes and No Holes Variables Underlying Packed Conduit Permeability

Table 1A-1															
Sample	η	ρ_f	D	L	Ω_p	d_{pm}	d_p	n_p	k	ε_p	n_{pq}	p_f	ε_0	d_c	Ratio
ID	Ind. Var.	Ind. Var.	Ind. Var.	Ind. Var.	d_p	d_{pm}		Ind. Var.	Ind. Var.	Ind. Var.	V_{sc}	n_p	$(1-n_p/n_{pq})$	$d_p/ p_f $	$\overline{D}$
					d_{pm}						v_{dp}	n_{pq}			d_p
Dixon 2026	poise	gcm^{-3}	cm	cm	none	cm	cm	none	cm	none	none	none	none	cm	none
$n_p = 55$															
Holes	0.010	1.000	6.00	14.00	0.933	2.0000	1.8663	55	0.0000	0.000	116.30	0.4729	0.5271	3.9464	3.2
Full	0.010	1.000	6.00	14.00	1.000	2.0000	2.0000	55	0.0000	0.000	94.50	0.5848	0.4152	3.4200	3.0
$n_p = 124$															
Holes	0.010	1.000	10.00	12.80	0.962	2.0000	1.9250	124	0.0000	0.000	269.18	0.4607	0.5393	4.1786	5.2
Full	0.010	1.000	10.00	12.80	1.000	2.0000	2.0000	137	0.0000	0.000	240.00	0.5706	0.4294	3.5051	5.0
$n_p = 124$															
Holes	0.010	1.000	10.00	12.80	1.000	2.0000	1.9995	124	0.0000	0.000	240.19	0.5163	0.4837	3.8730	5.0
Full	0.010	1.000	10.00	12.85	1.000	2.0000	2.0000	137	0.0000	0.000	240.94	0.5706	0.4294	3.5051	5.0
$n_p = 124$															
Holes	0.01	1.00	10.00	12.80	1.023	2.0000	2.0456	124	0.0000	0.000	224.31	0.5528	0.4472	3.7003	4.9
Full	0.010	1.00	10.00	12.80	1.000	2.0000	2.0000	137	0.0000	0.000	240.00	0.5706	0.4294	3.5051	5.0
$n_p = 245$															
Holes	0.010	1.000	14.00	12.60	0.952	2.0000	1.9036	245	0.0000	0.000	537.02	0.4562	0.5438	4.1725	7.4
Full	0.010	1.000	14.00	12.80	1.000	2.0000	2.0000	249	0.0000	0.000	470.40	0.5285	0.4715	3.7846	7.0

In Table 1A-1, the teaching of the QFFM is employed to demonstrate the apples-to-oranges comparison by the original paper authors of the underlying variables of packed conduits containing perforated particles (with holes) and particles with solid spheres (no holes).

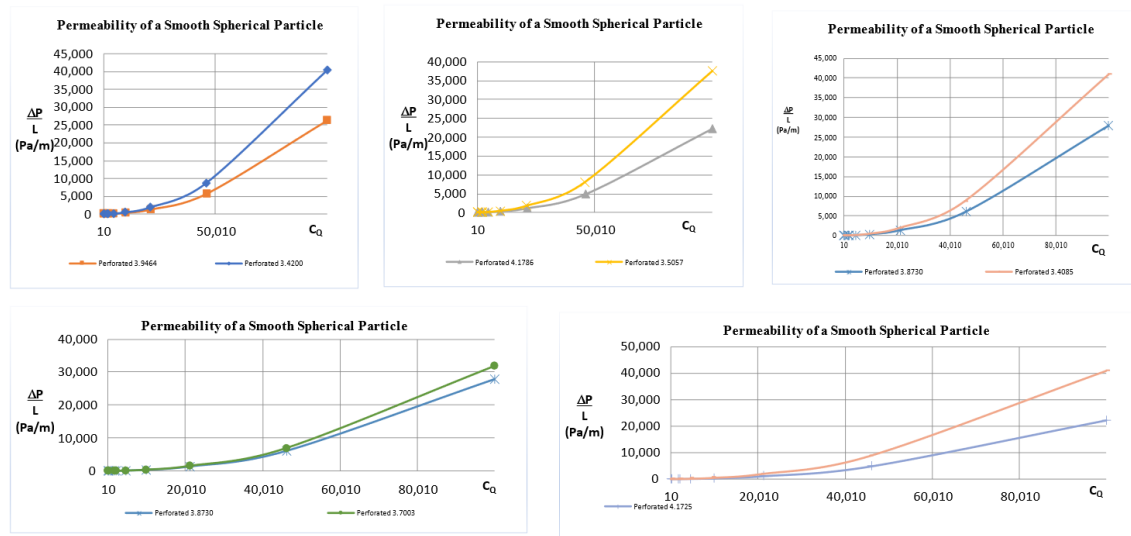
Underlying Explanation #1: Apples-to-Oranges Comparison.

1. This table shows two packed conduits for each category of experiment corresponding to the scenarios reported by the original paper authors; one contains the particles with holes; one contains solid spherical particles with no holes. There are 5 variations in all, each corresponding to the number of particles with holes reported for each conduit. Those variations are (1) $n_p = 55$, (2) $n_p = 124$, (3) $n_p = 124$, (4) $n_p = 124$, and (5) $n_p = 245$. This results in a total of 10 different packed conduits to establish a definitive comparison.
2. The fluid is water at 20°C, fluid absolute viscosity, η , = 0.01; fluid density ρ_f = 1.0.
3. The conduit diameter D is as reported in the paper (Table 1) for the perforated particle packed conduit.
4. The conduit length L is as reported in the paper (Table 1) for the perforated particle packed conduit.

5. The spherical particle diameter equivalent, d_p , is derived by the QFFM based upon the reported values in the paper for the external porosity ε_0 of the perforated particle packed conduit.
6. The particles with holes are represented as irregularly shaped particles with a sphericity factor, Ω_p other than unity (a value of $\Omega_p = 1$ is a perfect sphere).
7. The diameter of the full particles is designated $d_{pm} = 2.00$ cm as specified in the paper.
8. The number of particles n_p is as reported in the paper (Table 1) for the perforated packed conduit.
9. The particle sand roughness $k = 0$ since the particles are reported to have a smooth surface.
10. Note that the particle porosity $\varepsilon_p = 0$, meaning there are no **internal** pores in the particle skeleton since the holes (pores) are totally **external** to the solid particle skeleton.
11. The volume of the empty conduit $n_{pq} = (V_{ec}/V_{dp})$, is expressed as number of particle equivalents, where V_{ec} = volume of empty conduit and V_{dp} = volume of a single particle.
12. The solid particle volume fraction $p_f = (n_p/n_{pq})$
13. The values for the external porosity, ε_0 , are as reported in the paper (Table 1) for both packed conduits and, in the QFFM, this term is defined as $\varepsilon_0 = (1 - n_p/n_{pq})$
14. The diameter of the Hypothetical Q Channel (HQC) in the QFFM is defined as $d_c = (d_p/\text{abs}(p_f))$ and has a different value for each category of packed particle conduit. This is one of the features that defines the apples-to-oranges designation.
15. Note that the ratio of D/d_p is based upon the reported value of D for the perforated particle packed conduit diameter and the QFFM calculated value of d_p . It has a different value for each pair of conduits which is another one of the features that establishes this comparison as apples-to-oranges.

Apples-to-Oranges Permeability Comparison With and Without Holes

Fig 1A



In Fig 1A, the plot shows the apples-to-oranges comparison for each pair of packed conduits. Note that there are a total of 10 lines indicating that each of the conduits have a different permeability. In other words, not only do the conduits possess different type particles, they also demonstrate different pressure drop characteristics. Accordingly, this comparison involves changing at least two variables at the same time.

Table 1A-2

Apples-to-Apples Comparison of Holes and No Holes Variables Underlying Packed Conduit Permeability

Table 1A-2															
Sample	η	ρ_f	D	L	Ω_p	d_{pm}	d_p	n_p	k	ε_p	n_{pq}	p_f	ε_0	d_c	Ratio
ID	Ind. Var.	Ind. Var.	Ind. Var.	Ind. Var.	$\frac{d_p}{d_{pm}}$	d_{pm}		Ind. Var.	Ind. Var.	Ind. Var.	$\frac{V_{pc}}{V_{pc}}$	n_{pq}	$(1-n_p/n_{pq})$	$d_p/ p_f $	$\frac{D}{d_p}$
					d_{pm}						v_{dp}	n_{pq}			d_p
Dixon 2026	poise	gcm^{-3}	cm	cm	none	cm	cm	none	cm	none	none	none	none	cm	none
$n_p = 55$															
Holes	0.010	1.000	6.00	14.00	0.933	2.0000	1.8663	55	0.0000	0.000	116.30	0.4729	0.5271	3.9464	3.2
Full	0.010	1.000	6.42	14.04	1.000	2.0000	2.0000	55	0.0000	0.000	108.53	0.5068	0.4932	3.9464	3.2
HQC (vector)	0.010	1.000	3.95	15.18	1.000	3.9464	3.9464	-6	0.0000	1.000	5.77	-1.0000	2.0000	3.9464	1.0
$n_p = 124$															
Holes	0.010	1.000	10.00	12.80	0.962	2.0000	1.9250	124	0.0000	0.000	269.18	0.4607	0.5393	4.1786	5.2
Full	0.010	1.000	10.38	12.80	1.000	2.0000	2.0000	124	0.0000	0.000	258.59	0.4786	0.5214	4.1786	5.2
HQC (vector)	0.010	1.000	4.18	10.00	1.000	4.1786	4.1786	-4	0.0000	1.000	3.59	-1.0000	2.0000	4.1786	1.0
$n_p = 124$															
Holes	0.010	1.000	10.00	12.80	1.000	2.0000	1.9995	124	0.0000	0.000	240.19	0.5163	0.4837	3.8730	5.0
Full	0.010	1.000	10.00	12.85	1.000	2.0000	2.0000	124	0.0000	0.000	240.94	0.5164	0.4836	3.8730	5.0
HQC (vector)	0.010	1.000	3.87	10.00	1.000	3.8730	3.8730	-4	0.0000	1.000	3.87	-1.0000	2.0000	3.8730	1.0
$n_p = 124$															
Holes	0.01	1.00	10.00	12.80	1.023	2.0000	2.0456	124	0.0000	0.000	224.31	0.5528	0.4472	3.7003	4.9
Full	0.010	1.000	9.78	12.80	1.000	2.0000	2.0000	124	0.0000	0.000	229.56	0.5405	0.4595	3.7003	4.9
HQC (vector)	0.010	1.000	3.70	10.00	1.000	3.7003	3.7003	-4	0.0000	1.000	4.05	-1.0000	2.0000	3.7003	1.0
$n_p = 245$															
Holes	0.010	1.000	14.00	12.60	0.952	2.0000	1.9036	245	0.0000	0.000	537.02	0.4562	0.5438	4.1725	7.4
Full	0.010	1.000	14.70	12.80	1.000	2.0000	2.0000	249	0.0000	0.000	518.62	0.4793	0.5207	4.1725	7.4
HQC (vector)	0.010	1.000	4.17	10.00	1.000	4.1725	4.1725	-4	0.0000	1.000	3.59	-1.0000	2.0000	4.1725	1.0

Underlying Explanation #2: Apples-to-Apples Comparison.

1. In this Table another category is included in the comparison. This is the HQC for an equivalent empty conduit. It is included to provide an independent reference point since the authors of the original paper used the Reynolds number as their governing equation. The comparison now contains a total of 15 packed conduits.
2. In this scenario the variables for the equivalent packed conduit with full particles are chosen such that for each category the term d_c is identical. This makes the comparison apples-to-apples.
3. The diameter of the (HQC), d_c is the unifying parameter that renders the packed conduits hydrodynamically equivalent.
4. Note that the ratio D/d_p is also identical for each pair of packed conduits.

Apples-to-Apples Permeability Comparison With and Without Holes

Fig 1B

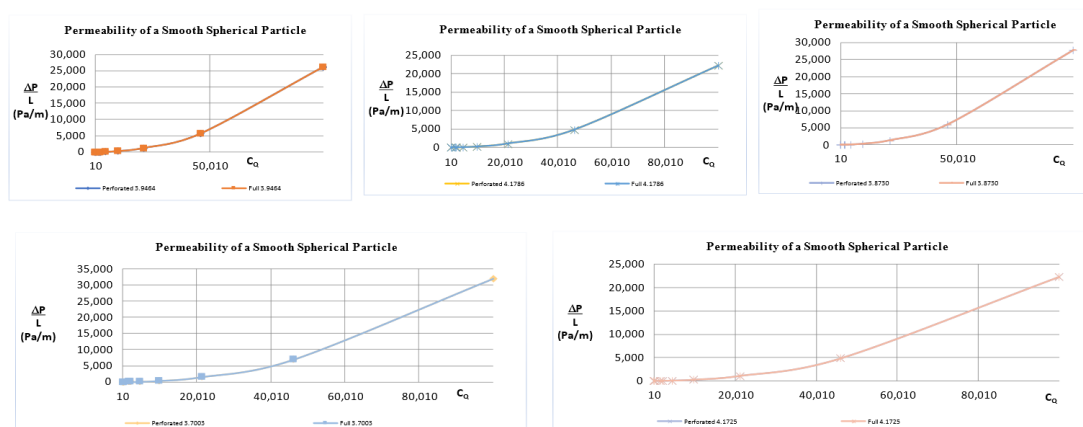


Fig 1B

In Fig 1B, the plot shows the apples-to-apples comparison for each pair of packed conduits. Note that there are just 5 lines which means that each pair of packed conduits have identical pressure drop characteristics. Accordingly, this demonstrates that only one variable is changed in this comparison, i.e., the difference of the particles inside the conduits.

Table 1B**Apples-to-Apples Comparison of Holes and No Holes
Variables Underlying Packed Conduit Permeability**

Table 1B Sample ID	δ $\frac{1}{\varepsilon_0^3}$	γ $\frac{3D^2L}{2d_p^3}$	$\tau = \delta\gamma$ $\frac{3D^2L}{2d_p^3\varepsilon_0^3}$	λ $I+W_N$	ω $\frac{\lambda}{8\pi}$	T $\frac{2\pi}{\omega}$	t_Q $\frac{\delta\lambda L d_p \varepsilon_0 \rho_f}{\eta}$	TTP $\frac{\delta\lambda Re_{m-c}}{C_{Q-C}}$	TTP Re_{m-c}	A $\frac{4\pi \varepsilon_0^3}{3}$	B $\frac{\delta\lambda}{2\pi}$	Range C_Q	Range P_Q
Dixon 2026 $n_p = 55$	none	none	none	none	rad/sec	sec	sec	none	none	none	none	none	none
Holes	6.829	50	340	1.002	0.04	158	19,933	1,686	246	268.19	1.089	1-100,000	0-4,000
Full	8.335	50	414	1.002	0.04	158	22,828	1,686	202	268.19	1.329	1-100,001	0-4,000
HQC	0.125	1.50	0.188	6.070	0.24	26	4,545	1,686	2,222	268.19	0.121	1-100,002	0-4,000
$n_p = 124$													
Holes	6.374	210	1340	1.001	0.04	158	18,399	1,686	264	268.19	1.015	1-100,000	0-4,000
Full	7.056	210	1480	1.001	0.04	158	19,687	1,686	239	268.19	1.123	1-100,001	0-4,000
HQC	0.125	1.50	0.188	6.070	0.24	26	3,171	1,686	2,222	268.19	0.121	1-100,002	0-4,000
$n_p = 124$													
Holes	8.834	188	1658	1.000	0.04	158	21,195	1,686	191	268.19	1.406	1-100,000	0-4,000
Full	8.842	188	1658	1.000	0.04	158	21,290	1,686	191	268.19	1.407	1-100,001	0-4,000
HQC	0.125	1.50	0.188	6.070	0.24	26	2,939	1,686	2,222	268.19	0.121	1-100,002	0-4,000
$n_p = 124$													
Holes	11.183	175	1960	1.000	0.04	158	377	1,686	151	268.19	1.780	1-100,000	0-4,000
Full	10.307	175	1808	1.000	0.04	158	22,442	1,686	163	268.19	1.641	1-100,001	0-4,000
HQC	0.125	1.50	0.188	6.070	0.24	26	2,808	1,686	2,222	268.19	0.121	1-100,002	0-4,000
$n_p = 245$													
Holes	6.219	597	3711	1.000	0.04	158	17,784	1,686	271	268.19	0.990	1-100,000	0-4,000
Full	7.084	596	4219	1.000	0.04	158	19,704	1,686	238	268.19	1.127	1-100,001	0-4,000
HQC	0.125	1.50	0.188	6.070	0.24	26	3,166	1,686	2,222	268.19	0.121	1-100,002	0-4,000

In Table 1B, the results of the QFFM calculated parameters are shown for all hydrodynamically equivalent conduits.

Underlying Explanation #3: Calculated QFFM Parameters

1. Note that the QFFM uniquely defines the term $\delta = (1/\varepsilon_0^3)$ which is an additional term necessary to establish hydrodynamic equivalency based upon kinetic contributions to pressure drop.
2. The QFFM parameter $\gamma = n_{pq}D/L = 3D^2L/(2d_p^3)$ is the architectural feature of a packed conduit.
3. The QFFM parameter $\tau = \delta\gamma = 3D^2L/(2d_p^3\varepsilon_0^3)$ is the fluid path tortuosity.
4. The values of λ , the wall-effect normalization coefficient, is identical for each category of solid particles under comparison.
5. The value of the ω parameter is identical for the two categories of solid particle conduits under comparison.
6. The value of the T parameter is identical for the two categories of solid particle conduits under comparison.
7. The value of the critical C_Q parameter, C_{Q-C} , at the TTP is identical at the value of $C_Q = 1,686$ for all 15 conduits under study.
8. The value of the critical Re_m parameter, Re_{m-c} , at the TTP varies for all conduits having solid particles but has the unique value of $Re_{m-c} = 2,222$ for all empty conduits.
9. The value of the A coefficient in the Q modified Ergun model has the constant value of 268.19 for all 15 conduits.
10. The value of the B coefficient in the Q modified Ergun model varies for each of the solid particle packed conduits but has a constant value for all empty conduits.

11. Since the QFFM is valid over the entire fluid flow regime, the range of flow rates is much larger than that chosen by the original paper authors. This is because the reported range of flow rates has no particular apparent relevance since the entire scenario presented in the paper is theoretical and does not include a single measurement.

Table 1C

**Apples-to-Apples Comparison of Holes and No Holes
QFFM Solver**

Table 1C	a_{FOR}	b_{FOR}	λ	δ/d_c^2	δ^2/d_c	δ^3/d_c^3	δ/d_c	$\lambda/(\delta d_c)$	d_c	δ	ε_0	d_p
$\frac{3D^2L(1-\varepsilon_0)}{4r_h^3\pi\delta\eta}$	$\frac{3\rho g d_c^2}{s/cm}$	$\frac{2\pi g d_c}{s^2/cm^2}$	$1+W_N$	$\frac{3a\rho g}{4r_h^3\pi\eta}$	$\frac{2b\pi g}{\lambda}$	$X = \alpha\beta$	$X^{1/3}$	$Y = \alpha/\beta$	$1/(X^{1/6}Y^{1/2})$	$X^{1/6}/Y^{1/2}$	$Y^{1/6}/X^{1/16}$	
Dixon 2026			none	α	β	cm^{-3}	cm^{-1}	cm^{-1}	cm	none	none	cm
$n_p = 55$												
Holes	0.001198	0.001920	1.002	0.4384	11.81	5.18	1.73	0.0371	3.95	6.83	0.527	1.87
Full	0.001464	0.002862	1.002	0.5353	17.61	9.43	2.11	0.0304	3.95	8.34	0.493	2.00
HQC (vector)	0.000022	0.000004	6.066	0.0080	0.00	0.00	0.03	2.0261	3.95	0.13	2.000	3.95
$n_p = 124$												
Holes	0.000998	0.001579	1.001	0.3652	9.73	3.55	1.53	0.0375	4.18	6.38	0.539	1.93
Full	0.001105	0.001933	1.001	0.4040	11.91	4.81	1.69	0.0339	4.18	7.06	0.521	2.00
HQC (vector)	0.000020	0.000004	6.070	0.0072	0.00	0.00	0.03	1.9063	4.18	0.13	1.998	4.18
$n_p = 124$												
Holes	0.001611	0.003272	1.000	0.5891	20.16	11.88	2.28	0.0292	3.87	8.84	0.484	2.00
Full	0.001611	0.003275	1.000	0.5894	20.18	11.90	2.28	0.0292	3.87	8.84	0.484	2.00
HQC (vector)	0.000023	0.000004	6.046	0.0083	0.00	0.00	0.03	2.0578	3.88	0.13	1.998	3.87
$n_p = 124$												
Holes	0.002232	0.005478	1.000	0.8164	33.77	27.57	3.02	0.0242	3.70	11.18	0.447	2.05
Full	0.002057	0.004656	1.000	0.7525	28.70	21.60	2.78	0.0262	3.70	10.30	0.460	2.00
HQC (vector)	0.000025	0.000004	6.074	0.0091	0.00	0.00	0.03	2.1710	3.69	0.12	2.002	3.70
$n_p = 245$												
Holes	0.000977	0.001504	1.000	0.3573	9.27	3.31	1.49	0.0385	4.17	6.22	0.544	1.90
Full	0.001112	0.001951	1.000	0.4069	12.03	4.89	1.70	0.0338	4.17	7.08	0.521	2.00
HQC (vector)	0.000020	0.000004	6.069	0.0072	0.00	0.00	0.03	1.9165	4.17	0.13	2.000	4.17

In Table 1C, the QFFM solver which is used as the methodology to establish hydrodynamic equivalency between the two different conduit types, is shown.

Underlying Explanation # 4. The QFFM Solver

1. This table shows the various mathematical constructs used to back-calculate from measured permeability the critical values of ε_0 and d_p and, thus, the value of the diameter of the HQC d_c .
2. The QFFM solver is based upon the teaching of Forchheimer circa 1920 which establishes the Forchheimer coefficients a_{FOR} and b_{FOR} .
3. The term λ in the QFFM is a measure of the wall-effect. A value for $\lambda = 1$ represents no wall effect.
4. The values back-calculated for ε_0 and d_p constitute a simultaneous solution based upon measured permeability as taught by the Forchheimer flow model. Accordingly, both these variables are dependent variables in the pressure flow relationship.

The Hypothetical Q Channel (HQC) With and without Holes

Fig 1

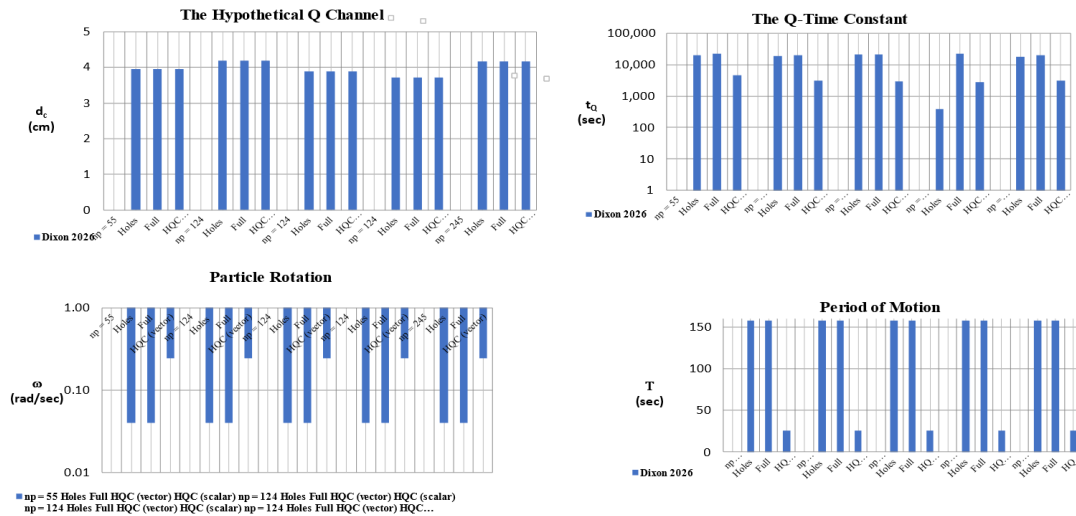


Fig. 1

In Fig 1, an apples-to-apples comparison of each of the 3 categories of conduits, is presented. Note that the value of d_c is identical for each category of conduit. An exact explanation for each of these parameters is outside the scope of this paper but we refer the reader to the original publication of the QFFM in 2019.

Apples-to-Apples Permeability Comparison With and Without Holes

Fig 1A

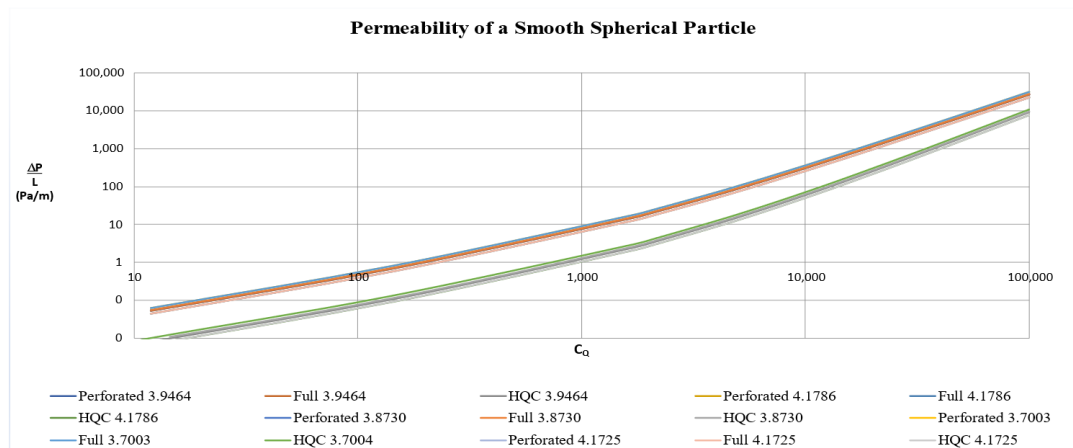
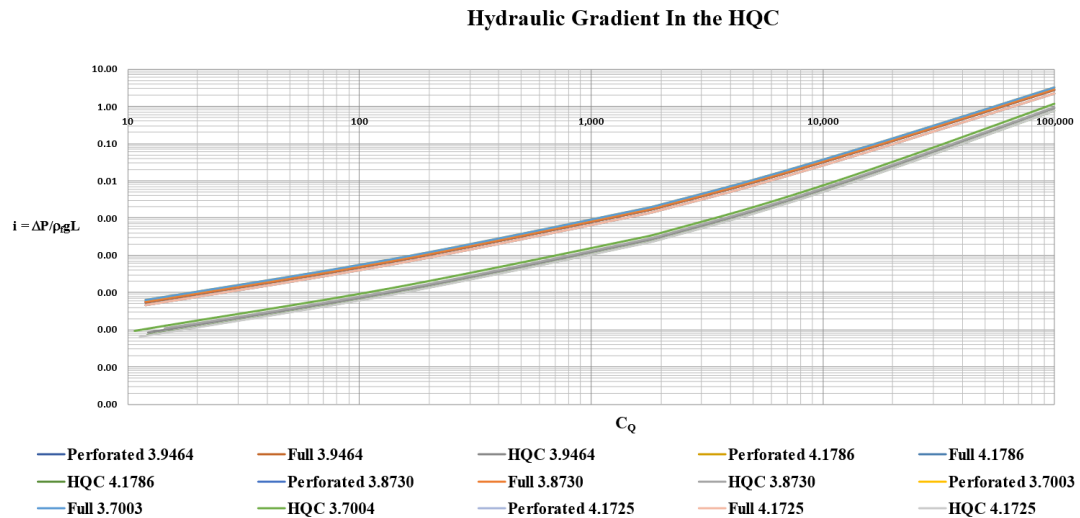


Fig 1A

Fig1A shows an apples-to-apples comparison of permeability between all 15 packed conduits. Note that there are just 5 lines in the plot for the conduits containing particles with solid skeletons and 5 lines in the plot for the empty conduits. In other words, the hydrodynamically equivalent packed conduits using particles of either type have the exact same data for permeability expressed in this plot as pressure drop $\Delta P/L$ (Pa/m) versus dimensionless fluid current C_0 .

Apples –to-Apples Comparison of Hydraulic Gradient

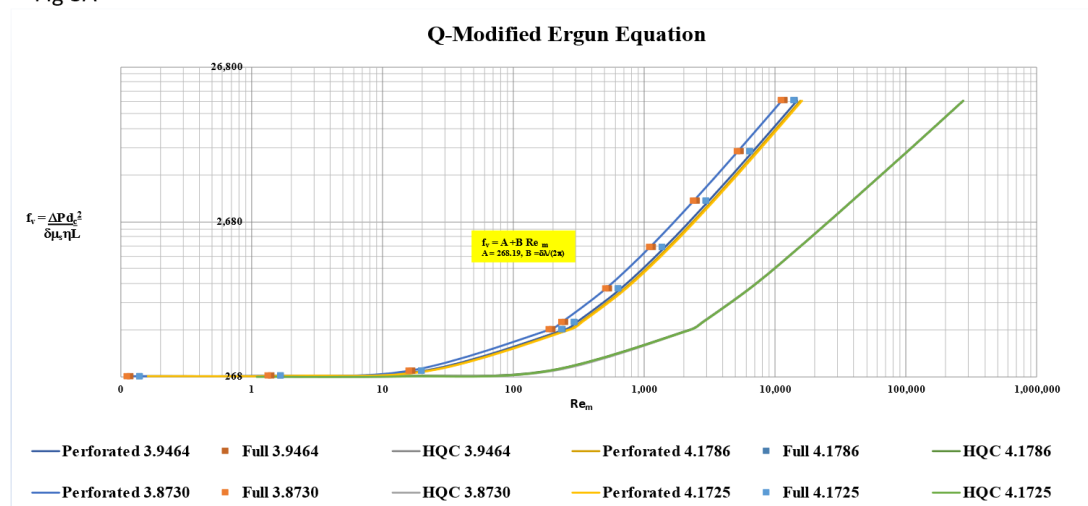
Fig 2A

**Fig 2A**

In Fig2A we show an apples-to-apples comparison of hydraulic gradient between all 15 packed conduits. Note that the hydrodynamically equivalent packed conduits containing the solid particles have the exact same data for hydraulic gradient in each category expressed in this plot as hydraulic gradient, $i = (\Delta P / r_f g L)$ versus dimensionless fluid current $C_Q = dL Re_m$.

Apples-to-Apples Comparison of A Viscous Type friction Factor

Fig 3A

**Fig 3A**

In Fig 3A, the data for all 15 packed conduits is shown. Note that this highlights the difference in the value of external porosity, ε_0 , for each category.

Apples-to-Apples Comparison of Dimensionless Permeability A Reciprocal Kinetic Type Friction Factor

Fig 4A

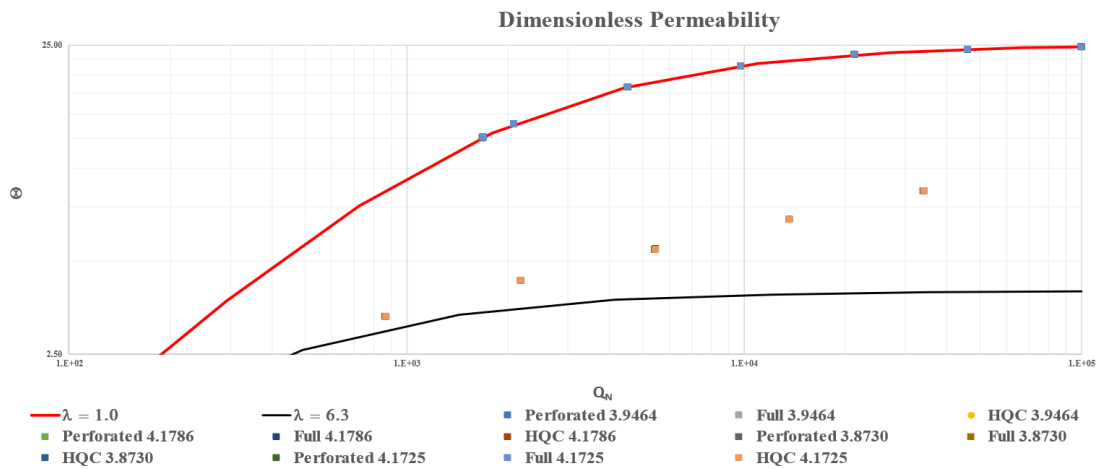


Fig 4A

In Fig 4A, the dimensionless permeability data for all 15 packed conduits is shown. Note that this plot underlines the wall-effect for all categories of conduits. Note that all conduits containing particles with solid skeletons fall on the line for $\lambda = 1$ which demonstrates that the wall effect is virtually negligible.

The QFFM Universal Friction Factor Quinn's Law of Fluid Dynamics

Fig 5A

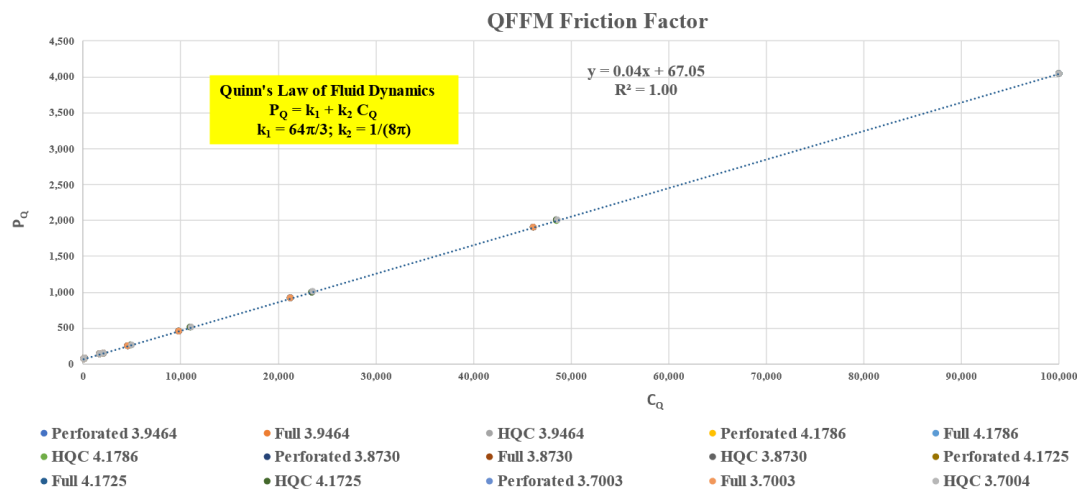


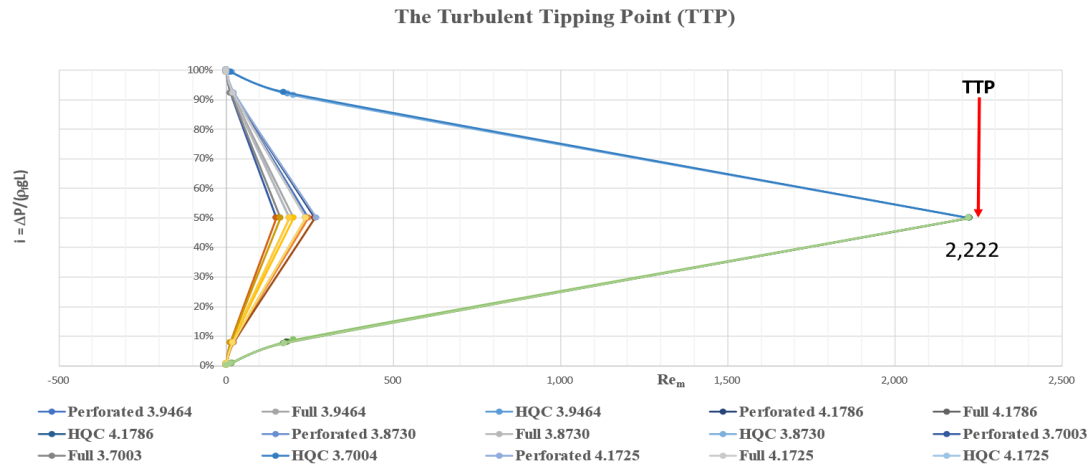
Fig 5A

On the other hand, note that the empty conduits all have the same very large wall effect due to a comparable viscous boundary layer, but which becomes increasingly dissipated at higher flow rates.

In Fig 5A, the data for all 15 packed conduits is shown. Note that all data for the 15 packed conduits fall on the same straight line. This represents the universal pressure/flow relationship properly normalized for all relationship variables.

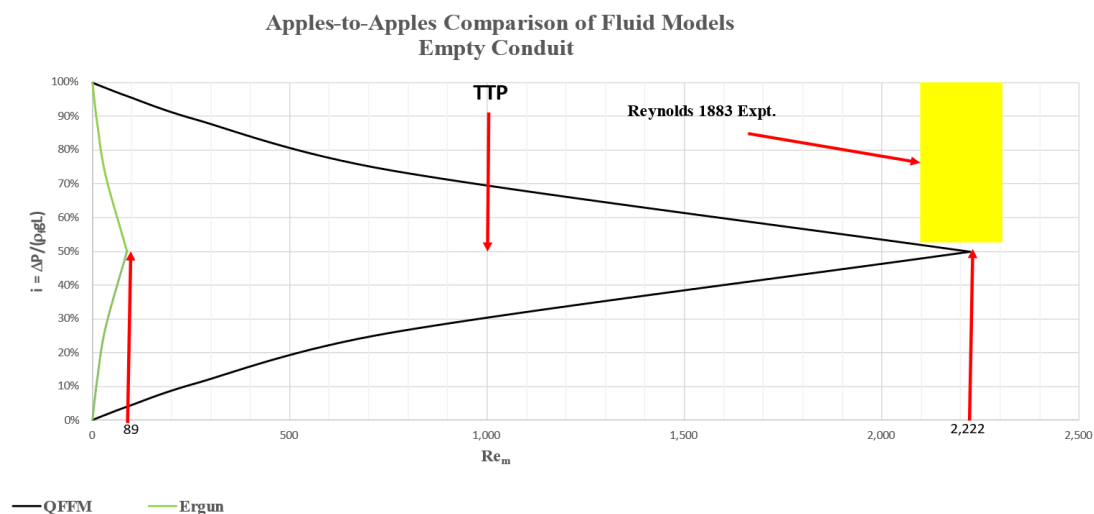
The Turbulent Tipping Point (TTP)

Fig 6A

**Fig 6A**

In Fig 6A, the turbulent tipping point, which is the point at which viscous and kinetic contributions to pressure drop are equivalent, is shown for all 15 packed conduits. Note that there is a significant difference between conduits containing particles with solid skeletons and empty conduits. Note also that all empty conduits have the critical value of the modified Reynolds number $Re_m = 2,222$ at the TTP.

Apples-to-Apples Comparison of The Ergun and QFFM Models

**Fig 7A**

In Fig 7A, the incompatibility of the Ergun and Reynolds number models is demonstrated based upon application of both models to an empty conduit. As shown in the plot, on the one hand, the QFFM and Reynolds number models are shown to reconcile in a hand-in-glove correlation at the TTP based upon the observations of Sir Osborne Reynolds in his 1883 experiment wherein he reported the range of 2100 to 2300 for his newly minted Reynolds number values. The validated value for the TTP in the QFFM model is 2,222 just about in the middle of this range. On the other hand, the Ergun model understates significantly, at a value of 89 approx., the value range of 2100 to 2300 reported by Reynolds in 1883. This makes the Ergun and Reynolds flow models incompatible. This incompatibility of the flow models is routed in the erroneous values of 150 and 1.75 for the two built-in coefficients A and B, respectively in the Ergun model. We have included this plot to establish context for our comments regarding our objections to the original paper authors use of the Ergun and Reynolds number models.

CONCLUSIONS

Based upon the apples-to-apples comparison of the two categories of packed conduits in this paper, the following conclusions are drawn:

1. Particle shape plays no role in packed conduit permeability when the characteristic dimension of the particles are expressed in terms of the average spherical particle diameter equivalent d_p .
2. This conclusion follows from the sinuous nature of the fluid flow in packed conduits which is driven by the fluid path tortuosity which, in turn, is driven by the architectural makeup of any packed conduit under study.
3. The use of perforated particles in this paper under study does not affect the packed conduit performance when compared to solid particles with no holes, when all other variables are normalized, i.e., an apples-to-apples comparison.
4. In the paper under study, no theoretical evidence was presented by the original authors to establish the role of particle shape, since all evidence was based upon apples-to-oranges comparisons.
5. The use of the Ergun model in conjunction with the conventional Reynolds number renders the conclusions by the authors of the paper under study to be troublesome.
6. Finally, the only valid methodology to evaluate particle shape is to pack, unpack and repack, hydrodynamically equivalent packed conduits many times with the same actual number of particles in the same empty conduits and measure the permeability. If particle shape plays a role, then the permeability will vary for each repacked conduit because in performing the act of packing a conduit with spherical particles no two attempts deliver the same particle arrangements. The original authors of this paper never produced this experimental result because they never made a single measurement. Their paper was all theoretical, i.e., pure speculation.
7. In over 40 years of packing irregularly shaped particles, unpacking and repacking solid spherical glass beads, this author can report, based upon measured data for more than 100,000 packed conduits produced for sale to paying customers, not

theoretical speculation, particle shape plays no role, whatsoever, in the permeability of packed conduits.

8. As an additional note to those who think that theory trumps measurement, it should be noted that an empty conduit contains particles of free space and, accordingly, it does not matter which way you orient a particle of free space, because its physical characteristic and, consequently, its permeability characteristic, does not change. If, however, you create an empty conduit by placing holes in the hypothetical particles of a given empty conduit under study, this changes the value of d_c the diameter of the HQC and therein lies the genesis of the apples-to oranges comparison used by the original authors of this paper under study.

REFERENCES

List of Publications

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

List of Publications Cont'd

14	Quinn	H M	The Solution Equivalent of the Navier -Stokes Equation in HPLC	SCIREA Journal of Mechanics Volume 4, Issue 1, February 2023	2023
15	Quinn	H M	A Rebuttal Paper	European Journal of Applied Sciences Vol. 12 No. 6 (2024):835846 DOI:10.14738/aivp.126.18091.	2024
16	Quinn	H M	A Critique By Hubert M Quinn, The Wrangler Group LLC, 40 Nottinghill Road, Brighton, Ma. 02135	SCIREA Journal of Information Science and Systems Science. Volume 9, Issue 1, February 2025 PP. 1-10. DOI:10.54647/1sss.12037	2025
17	Quinn	H M	Columns Hydrodynamics in Packed Beds with Particular Focus on UHLC The Wrangler Group LLC, 40 Nottinghill Road, Brighton, Ma. 02135	Chem Pharm Res. 2025; Volume 7 (1): 1-10.	2025
18	Quinn	H M	A Comparison of Sir Osborne Reynold's 1883 Seminal paper and the QFFM; A Hand in Glove Reconciliation	European Journal of Applied Sciences Vol. 13 No. 4 (2025):71-92. DOI:10.14738/aivp.1304.19134.	2025
19	Nikitin Quinn Pashchenko	M H M D	Flow through packed beds: Experimental and numerical validation of the Quinn fluid flow model	Physics of Fluids Vol. 37, 084113 (2025) DOI:10.1063/5.0283733	2025
20	Papkov Quinn Pashchenko	V H M D	Flow through randomly packed beds of rough particles: Model prediction and experimental validation	Physics of Fluids Vol. 37, 103318 (2025) DOI:10.1063/5.0293302	2025
21	Quinn Pashchenko	H M D V	A New Semi-empirical Model for Pressure Drop Prediction in a Packed Bed of Smooth and Rough Particles: Derivation and Verification	Physics of Fluids Vol. 38, 016101 (2026) doi:10.1063/5.0314530	2026
22	Quinn	H M	The 12 Principles of Fluid Dynamics in Closed Conduits Aerodynamic Analysis of a Golf Ball in Flight.	Journal of Physical Mathematics & its Applications. SRC/IPMA-190. DOI: doi.org/10.47363/IPMA/2026(4)155	2026
23	Quinn	H M	The Quinn Fluid Flow Model (OFFM)	Journal of Advanced Artificial Intelligence Research	2026