NEW PROPOSED FORMULATIONS FOR THE CALCULATION OF HYDRAULIC CONDUCTIONS

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NUEVAS FORMULACIONES PROPUESTAS PARA EL CÁLCULO DE LAS CONDUCCIONES HIDRÁULICAS

ABSTRACT:

The present work aims to improve the results offered by the application of classic formulas for the calculation of free lines, taking account of the differences observed in the engineering practice with the implementation of those. In this way, the author proposes twelve new formulas to calculate these channels according to the different frictions, together with a multiple model of universal application.

The methodology is based on the testing of statistical hypotheses which probably constitutes the most fertile contribution of the statistical-mathematical methods to accept o to refuse hypothesis and theories in any scientific field that has to be contrasted to reality, and also to solve less scientific but of undoubted practical value problems as those involved in Hydrology and Hydraulics.

All these considerations were already taken into account by the author in his previous book called "Five themes of Hydrology and Hydraulics" in which in Chapter I, several formulas for the calculus in free conductions were used following the statistical methodology. Those formulas are now the basis to calculate new ones adapted to forced, or under pressure, conductions. In this case the author is not using a unique formula, but he proposes a different one for each type of material, in order to achieve more accurate calculations. The formulas are established in accordance with six categories of roughness and five intermediate.

To reinforce this line of work, a test was performed in three different pipes (PVC, HDPE and asbestos-cement), studying the theoretical values of a group of hydraulic parameters both with universal used formulas and with those here proposed. The experiment clearly showed that these formulas gave better results in the calculus and the measuring of the real values for forced conductions.

Keywords: channel, hydraulic radio, flow, pressure, speed, head loss, formula and pipeline.

RESUMEN:

En el presente trabajo se propone mejorar los resultados ofrecidos por la aplicación de las fórmulas clásicas para el cálculo de las conducciones libres y forzadas, habida cuenta de las diferencias que se observan en la práctica ingenieril con la aplicación de aquellas. Y así, se proponen por el autor 12 nuevas fórmulas para el cálculo de las conducciones libres, según las diferentes categorías de rugosidad, junto con un modelo múltiple de aplicación universal.

La metodología se basa en la contrastación de hipótesis estadísticas que constituye, probablemente, la aportación más fecunda de los métodos estadístico-matemáticos para aceptar o rechazar hipótesis y teorías en cualquier campo científico que hayan de contrastarse con la realidad, o también para resolver problemas menos científicos pero de indudable valor práctico, cual es el caso de los que se plantean en la Hidrología y en la Hidráulica.

Todas estas consideraciones ya fueron tenidas en cuenta por este autor en su libro titulado "Cinco temas de Hidrología e Hidráulica", donde siguiendo precisamente la metodología estadística se elaboraron, en el Capítulo I de aquella obra, diversas formulaciones para el cálculo de las conducciones libres que ahora servirán de base para otras propuestas de formulación para el cálculo de las conducciones forzadas o a presión. Concretamente, en este caso el autor no dispone de una única fórmula, sino que propugna una diferente para cada tipo de material, con el objetivo de que los cálculos sean más exactos. Las fórmulas se establecen según seis categorías diferentes de rugosidad y cinco intermedias.

Así mismo, se realizó una prueba experimental con tres tuberías diferentes (de PVC, PEAD y amianto-cemento), cuyos parámetros hidráulicos fueron calculados por aplicación de diversas fórmulas universalmente reconocidas. No obstante, los resultados obtenidos de la experiencia realizada en las tres tuberías citadas ponen de manifiesto, una vez más, la bondad de la formulación que aquí se propone para el cálculo y dimensionamiento de las conducciones forzadas o a presión, que superó ampliamente a las demás en cuanto a su aproximación a los valores realmente obtenidos, como puede comprobarse.

Palabras clave: canal, radio hidráulico, caudal, presión, velocidad, pérdida de carga, fórmula, tubería.

1.- INTRODUCTION

When dimensioning open pipes, the found values of the average speed **V** and the circulating flow **Q** corresponding to a given motor slope **I**, for different hydraulic average radii **R**, result in the calculation differences obtained using the classical formulas of Bazin, Ganguillet and Kütter, the simplified one by Kütter, Biel, Forchheimer, Manning-Strickler and Koeschlin, raise serious doubts for the resolution of ordinary cases that arise in engineering practice. Possibly, the revision of these formulas would lose interest some time ago, since it was apparently a solved problem; On the other hand, we will dispense with an exhaustive review of the same: expression of their equations, justification, range of validity, coefficients, application cases ..., for obvious reasons of space. Of course, it is not intended to question here the validity of these formulations, which are universally recognized, although we do consider it necessary to develop our own formulations that statistically subsume the most relevant factors of the previous ones, while, through the coefficient de Fanning [1], facilitate its resolution for each of the twelve roughness categories considered (simple transformation) or for all of them together (multiple transformation).

2.- NEW FORMULAS FOR THE CALCULATION OF FREE DUCTS

In this way, once the corresponding calculation has been carried out, ten tables have been prepared (two for each of the five formulas studied, namely: Ganguillet and Kütter simplified, Manning-Strickler, Bazin, Koeschlin and Forchheimer) and another corresponding to the coefficient Fanning average, with different values of the Fanning coefficient λ for each of them depending on the two independent or explanatory variables of the problem: the degree of roughness of the walls and bottom K and the hydraulic average radius R. See tables 1-10 in additional document.
Next, the 12 different categories of roughness are established or defined (see table 12 in an additional document) and the mean de of each box is calculated (obtaining the arithmetic mean of the five homologous values using the corresponding spreadsheet). See table 11 in additional document.
For this, the different nature of the walls and the flooring of the open channels that are contemplated in the expressed formulations have been taken into account. In this way, a new table remains that summarizes, in one, the five classic formulations expressed.
The non-linear adjustment of each column (roughness) is calculated by means of the method of ordinary least squares (OLS) as a function of R, that is, obtaining the function: $\lambda = f(R)$, for each category of roughness. There will then be 12 least squares adjustments obtained by nonlinear regression. The trend lines, affected with their corresponding coefficients of co causality such as r^2, which is the determination or critical coefficient (which is very high in all cases, producing practically perfect correlations), as well as by the value of the "F" statistic They can be seen in table 13 of the additional document.
From this table we can deduce, in all the cases contemplated, fully satisfactory results.
In fact, the analyzed functional form has the analytical configuration:

$\lambda = AR^{-\alpha} = e^{-B} R^{-\alpha}$, where "A" is a constant and "e" is the base of the neperian or natural logarithms.

The speed formula is then applied and simplified:

$$V = \sqrt{\frac{2g}{\lambda}}\sqrt{RI} = \sqrt{\frac{2gRI}{\lambda}} \;,$$

substituting the value obtained from: $\lambda = f(R)$, which will leave 12 formulas (1 for each roughness category) as a function of R and I. They are the universal formulas proposed by this author.
In any case, for the 12 categories of roughness (1-12), substituting the values obtained, the following potential velocity functions will be had for each case. In the same way, for all cases, the direct use of the formula that offers the flow: $Q = SV$, and / or substituting the value of the average hydraulic radius for: $R = S / c$, where c is the wet contour or perimeter of the channel in question. Thus, the following expressions will be obtained:

K	V (m/s)	Q (m^3/s)
1	$\sqrt{\frac{2gRI}{0.0026\,R^{-0.243}}} = 86.85\,R^{0.6215}\,I^{0.5}$	$86.85\,c\,R^{1.6215}\,I^{0.5}$
2	$\sqrt{\frac{2gRI}{0.0032\,R^{-0.2691}}} = 78.29\,R^{0.63455}\,I^{0.5}$	$78.29\,c\,R^{1.63455}\,I^{0.5}$
3	$\sqrt{\frac{2gRI}{0.004\,R^{-0.2952}}} = 70.02\,R^{0.6476}\,I^{0.5}$	$70.02\,c\,R^{1.6476}\,I^{0.5}$
4	$\sqrt{\frac{2gRI}{0.0048\,R^{-0.3112}}} = 63.92\,R^{0.6556}\,I^{0.5}$	$63.92\,c\,R^{1.6556}\,I^{0.5}$
5	$\sqrt{\frac{2gRI}{0.0062\,R^{-0.3308}}} = 56.24\,R^{0.6654}\,I^{0.5}$	$56.24\,c\,R^{1.6654}\,I^{0.5}$
6	$\sqrt{\frac{2gRI}{0.008\,R^{-0.3545}}} = 49.51\,R^{0.67725}\,I^{0.5}$	$49.51\,c\,R^{1.67725}\,I^{0.5}$
7	$\sqrt{\frac{2gRI}{0.0102\,R^{-0.3665}}} = 43.85\,R^{0.68325}\,I^{0.5}$	$43.85\,c\,R^{1.68325}\,I^{0.5}$
8	$\sqrt{\frac{2gRI}{0.0133\,R^{-0.3914}}} = 38.4\,R^{0.6957}\,I^{0.5}$	$38.40\,c\,R^{1.6957}\,I^{0.5}$
9	$\sqrt{\frac{2gRI}{0.0197\,R^{-0.4166}}} = 31.55\,R^{0.7083}\,I^{0.5}$	$31.55\,c\,R^{1.7083}\,I^{0.5}$
10	$\sqrt{\frac{2gRI}{0.0268\,R^{-0.4222}}} = 27.05\,R^{0.7111}\,I^{0.5}$	$27.05\,c\,R^{1.7111}\,I^{0.5}$
11	$\sqrt{\frac{2gRI}{0.0364\,R^{-0.4332}}} = 23.21\,R^{0.7166}\,I^{0.5}$	$23.21\,c\,R^{1.7166}\,I^{0.5}$
12	$\sqrt{\frac{2gRI}{0.0514\,R^{-0.4384}}} = 19.53\,R^{0.7192}\,I^{0.5}$	$19.53\,c\,R^{1.7192}\,I^{0.5}$

Tabla 14. Proposed formulas for speed and flow.

Multivariate formulas have also been deduced for the calculation of speeds and flows, obtaining, for each assumption:

- **Roughness categories from 1 to 12 (general approximation)**:

$$V = \sqrt{\frac{2gRI}{R^{-0.3559}e^{-6.3388+0.2674\times K}}} = 4.43\sqrt{I\,R^{1.3559}e^{6.3388-0.2674\times K}}\quad .$$

- **Roughness categories from 1 to 6 (fine approximation)**:

$$V = \sqrt{\frac{2gRI}{R^{-0.3006}e^{-6.1766+0.2185\times K}}} = 4.43\sqrt{I\,R^{1.3006}e^{6.1766-0.2185\times K}}\quad .$$

- **Roughness categories from 7 to 12 (fine approximation)**:

$$V = \sqrt{\frac{2gRI}{R^{-0.4112}e^{-6.8639+0.3236\times K}}} = 4.43\sqrt{I\,R^{1.4112}e^{6.8639-0.3236\times K}}\quad .$$

The flow of the pipe, on the other hand, depending on the contour or wet perimeter c (taking into account that: $Q = S \cdot V$, $R = S / c$), will be given by the following expressions:

- **Roughness categories from 1 to 12 (general approximation)**:

$$Q = 4.43\ Rc\sqrt{I\ R^{1.3559}\ e^{6.3388-0.2674\times K}} = 4.43\ cI^{0.5}R^{1.67795}\ e^{3.1694-0.1337\times K}\ .$$

- **Roughness categories from 1 to 6 (fine approximation)**:

$$Q = 4.43\ Rc\sqrt{I\ R^{1.3006}\ e^{6.1766-0.2185\times K}} = 4.43\ cI^{0.5}R^{1.6503}\ e^{3.0883-0.10925\times K}\ .$$

- **Roughness categories from 7 to 12 (fine approximation)**:

$$Q = 4.43\ Rc\sqrt{I\ R^{1.4112}\ e^{6.8639-0.3236\times K}} = 4.43\ cI^{0.5}R^{1.7056}\ e^{3.43195-0.1618\times K}\ .$$

3.- NEW FORMULAS FOR THE CALCULATION OF FORZED DUCTS

3.1.- BACKGROUND

A more exhaustive explanation in this regard can be seen in “additional web material”.

3.2.- METHODS

It should be borne in mind that a relatively high number of formulations or tests should be handled, since the approximation will ordinarily grow with their number. And despite the irregular behavior of certain formulations or individual results (“outliers”), the average results, in long successions of experiences or formulations applied to solving the same problem, show surprising regularity [4].

In the case of forced or pressurized conduits, there are also disparate results in practice, depending on the formulation used. Well, identical formulations to those proposed by this author in the case of free pipes can be applied, with the corresponding corrections, in the calculation and design of forced pipes. For this, the formulas corresponding to the first 6 categories of roughness of free pipes have been used, and they are expressed below in the following table, depending on the tube material and for pipes used or in service.

These formulas, which can be applied independently of the hydraulic regime and the Reynolds number (Re) that characterizes the flow, will adopt the general configuration: $V = K_1 \cdot R^{\beta} \cdot J^{0.5}$, in which the speed (m/s) depending on the hydraulic radius (m) and the loss of unit pressure (m/ml). See table 15 of the additional document.

The previous formulation, however, is more practical to apply depending on the internal diameter (m) of the pipe and the flow (m^3/s) circulating through it, so, for the basic case studied (pipe in used or used), we would have, correlatively, the following expressions from table 16, in which the unit of pressure drop (m/m) has also been cleared and the intermediate formulas obtained by linear interpolation have been included:

Roughness (k)	V (m/s)	Q (m^3/s)	J (m/m)
1.0	**$36.69\ D^{0.6215}\ J^{0.5}$**	**$28.82\ D^{2.6215}\ J^{0.5}$**	**$0.000743\ V^2\ D^{-1.243}$**
1.5	$34.59\ D^{0.62802}\ J^{0.5}$	$27.16\ D^{2.62802}\ J^{0.5}$	$0.000845\ V^2\ D^{-1.256}$
2.0	**$32.48\ D^{0.63455}\ J^{0.5}$**	**$25.51\ D^{2.63455}\ J^{0.5}$**	**$0.000948\ V^2\ D^{-1.2691}$**
2.5	$30.51\ D^{0.6411}\ J^{0.5}$	$23.96\ D^{2.6411}\ J^{0.5}$	$0.001088\ V^2\ D^{-1.2821}$
3.0	**$28.53\ D^{0.6476}\ J^{0.5}$**	**$22.41\ D^{2.6476}\ J^{0.5}$**	**$0.001229\ V^2\ D^{-1.2952}$**
3.5	$27.14\ D^{0.6516}\ J^{0.5}$	$21.32\ D^{2.6516}\ J^{0.5}$	$0.001368\ V^2\ D^{-1.3032}$
4.0	**$25.76\ D^{0.6556}\ J^{0.5}$**	**$20.23\ D^{2.6556}\ J^{0.5}$**	**$0.001507\ V^2\ D^{-1.3112}$**
4.5	$24.06\ D^{0.6605}\ J^{0.5}$	$18.89\ D^{2.6605}\ J^{0.5}$	$0.001753\ V^2\ D^{-1.321}$
5.0	**$22.36\ D^{0.6654}\ J^{0.5}$**	**$17.56\ D^{2.6654}\ J^{0.5}$**	**$0.002\ V^2\ D^{-1.3308}$**
5.5	$20.86\ D^{0.6713}\ J^{0.5}$	$16.38\ D^{2.6713}\ J^{0.5}$	$0.002334\ V^2\ D^{-1.3426}$
6.0	**$19.36\ D^{0.67725}\ J^{0.5}$**	**$15.21\ D^{2.67725}\ J^{0.5}$**	**$0.002668\ V^2\ D^{-1.3545}$**

Source: self made.

Table 16. Proposed expressions of speed, flow and unit pressure drop for pipes in service.

These values should be multiplied by the relative roughness coefficients: α_2 (new tubes) or α_1 (semi-new tubes), defined by the author of this paper, if you want to refer to these new states of service or use. Likewise, according to the use or aging of the inner wall of the pipe, the adoption of the following corrections is proposed, which takes into account the evolution of the hydraulic radius:

$$\begin{cases} \text{For new pipes} & \rightarrow K'' = K \cdot \alpha_2 \\ \text{For semi-new pipes} & \rightarrow K' = K \cdot \alpha_1 \end{cases}$$

The estimated values of these relative roughness coefficients, α_1 and α_2, are set forth in table 17 of the additional document, for pipes subjected to normal wear, together with the absolute coefficients K_0, K_1 and K_2.

The proposed formulations have the advantage that, as in free conductions, the exponent of the J is, in all cases: $\nu = \frac{1}{2} = 0.5$ (however, this exponent, in relation to speed, can go from 0.5 in turbulent regime, which is the most normal, up to 1.0 in laminar regime); also in the explicit formula of J the exponent of the velocity V is m = 2.00, while the exponent of the internal diameter β increases progressively with the degree of roughness k, from 0.6215 to 0.67725.

In this same order of ideas, we can also use the multivariate expression obtained for free conductions, of the type $k \in (1,6)$; which would offer an average speed (m/s) of:

$$V = 4.43\ e^{3.0883-0.1093 \cdot k}\ R^{0.6503}\ J^{0.5}.$$

The methodology to apply is fundamentally statistical. The goodness or adjustment of the formulations that we propose becomes evident if they are compared with the results that other current formulas applicable to the case offer. Thus, for example, in the case of a cast iron pipe in service, the flow rates (expressed in l/s) that can be seen in table 18 would be obtained comparatively.

From the contemplation of said table it follows that the new formulation that we propose offers intermediate values for the used tubes, in all cases, as previously noted, and closer to the average value. A more illustrative and exact vision about the differences or "discrepancies" between the values calculated with each formulation and the mean of all of them, for each case, as well as the comparison with the "mean deviation from the arithmetic mean", can be seen in table 19, where in each box these discrepancies have been noted, that is, the values: $(q_i - \bar{q})$. The absolute mean deviation in relation to the arithmetic mean (which is minimal in relation to the median) will be given, in the last column of the previous table, by the expression:

$$DM = \frac{\sum_{i=1}^{5\text{ ó }6} \left| q_i - \bar{q} \right|}{5\text{ ó }6},$$

and represents a measure of absolute dispersion of the hydraulic variable "flow", for each case. To score the goodness of the approximation measure to the arithmetic mean, anyone who meets the condition is considered as “anomalous data” or “outlier”: $\left| qi - \bar{q} \right| \geq DM$. Thus, in the last row of the previous table, the number of outliers (abnormal results or "non-compliances") of each of the formulas studied has been indicated. The result thus obtained allows us to order these formulations due to their greater credibility due to their discrepancy in the value of the “arithmetic mean” of all of them, ultimately resulting in the following ranking in order of best to worst:

1. FRANQUET (0 outliers).
2. HAZEN-WILLIAMS (4 outliers).
3. BIEGELEISEN-BUKOWSKY (5 outliers).
4. DARCY (6 outliers).
5. BIEL (6 outliers, with 2 less tests).
6. KÜTTER (10 outliers).

Thus, the formulation resulting from our study has offered, in the 12 cases analyzed, results always below the absolute mean deviation in relation to the arithmetic mean, exceeding, at a considerable distance, its own [5], which is be the second best ranked based on these same criteria.

When we intend to compare magnitudes expressed in different units or in different situations, to be able to compare them we will have to make them homogeneous, and this process of homogenization of the different magnitudes requires their “typification” or “normalization”. Once the corresponding calculations have been carried out, table 20 has been prepared.

If we now compare the results offered by the sum of the absolute values of the typified variable for each formulation, it is observed that similar conclusions remain with those obtained by the application of the concept of "measure of approximation to the arithmetic mean". The formulation proposed in our work [6,7] continues to be the best, the [8] slightly exceeds that of Hazen-Williams and it should also be noted that the formulation of [9] has 2 less tests than to be performed They would undoubtedly worsen their results. As almost always, in short, the worst results are obtained by the formulations [10,11].

Subsequently, the confidence limits for the mean μ of the population of flows have been established in the event that the variance of the population of flows (measured empirically and / or estimated from a large number of “ad hoc” formulas) is unknown, as is the case at hand. Calculations have been made for the 12 cases, with a confidence level of 95%. To find the standardized value of the series, we will look in the t-Student table for a probability level of:

$0.95+\frac{0.05}{2}=0.975$, with 4 d.f. for the first two cases and 5 d.f. for the remaining 10.

Finally, to score the goodness of the formulations studied, table 21 has been prepared, in the last row of which the number of “non-compliances” or “rejections” appears, while in the last column the number of acceptances of each one of the 12 cases analyzed. On the 70 tests or situations, a total of 47 acceptances and 23 rejections are recorded, that is:

$\frac{47}{70}\times 100 \cong 67\%$ (acceptances) and 33% (rejections).

Also, the result of this new statistical analysis allows the previous formulations to be ordered by their highest degree of credibility, taking into account their 95% confidence interval, resulting, in short, in the following ranking in order of best to worst of the formulas in question:

1. FRANQUET (0 outliers)
2. BIEGELEISEN-BUKOWSKY (2 outliers)
3. HAZEN-WILLIAMS (3 outliers)
4. BIEL (3 outliers, with 2 less test or experiences)
5. DARCY (7 outliers)
6. KÜTTER (8 outliers)

Note that the results obtained from this new analysis give a classification quite similar to that resulting from the study of "discrepancies" between the values of the flows calculated with each formulation and the mean of all of them, for each of the 12 assumptions contemplated; although here, as has also been deduced from the study of the typing of the “flow” variable, the formulation of Biegeleisen-Bukowsky slightly surpasses that of Hazen-Williams. In addition, and this involves a certain perfectionist logic, its goodness undergoes a clear chronological progression.

It should be noted that both analyzes have started from the randomly chosen practical assumption proposed in the work [12], p. 138 and his appendix pp. 610-614, so it is not possible to suspect in this regard the carrying out of any type of manipulation or prior “adaptation” of the data or of the results obtained.

Finally, the study for new cast tubes has been repeated, replacing the first two formulations (Biel and Biegeleisen-Bukowsky) with [13,14]. The result thus obtained allows us to order these formulations due to their greater credibility due to their discrepancy in the value of the “arithmetic mean” of all of them, ultimately resulting in the following ranking in order of best to worst:

1. FRANQUET: (0 outliers).
2. LANG: (5 outliers).
3. HAZEN-WILLIAMS: (6 outliers).
4. KÜTTER: (6 outliers).
5. DARCY: (7 outliers).
6. LÉVY: (11 outliers).

Thus, the formulation derived from our study has offered, in the 12 cases analyzed, results always below the absolute mean deviation in relation to the arithmetic mean, surpassing, by a considerable distance, Lang's own, which turns out to be the second best. The typing and testing of hypotheses of the variable "flow" also offer totally favorable results for the proposed formulation.

3.3.- MATERIALS AND EXPERIMENTAL TEST

The test we carried out attempted to reflect the different comparisons between the theoretical data, obtained by the application of some of the different usual calculation formulas, and the practical data obtained by measurements carried out "in situ" in three pipes of POLYVINYL CHLORIDE (37 m and 56 mm inner diameter), HIGH DENSITY POLYETHYLENE (316 m and 113 mm inner diameter) and ASBESTOS CEMENT (95 m and 50 mm inner diameter) of the drinking water distribution network of the city of Tortosa (Tarragona, Spain) and different diameters. The precise data was provided by the Municipal Company of Public Services, S. L., of public capital in its entirety, which managed the corresponding drinking water supply service in said city, directly and efficiently. The PVC pipe was experimental and was expressly installed at the exit of one of the population's supply tanks in order to be able to carry out the corresponding calculations and deductions.

Next, the location plans of the other two pipes, which are part of the urban fabric of said city, are attached.

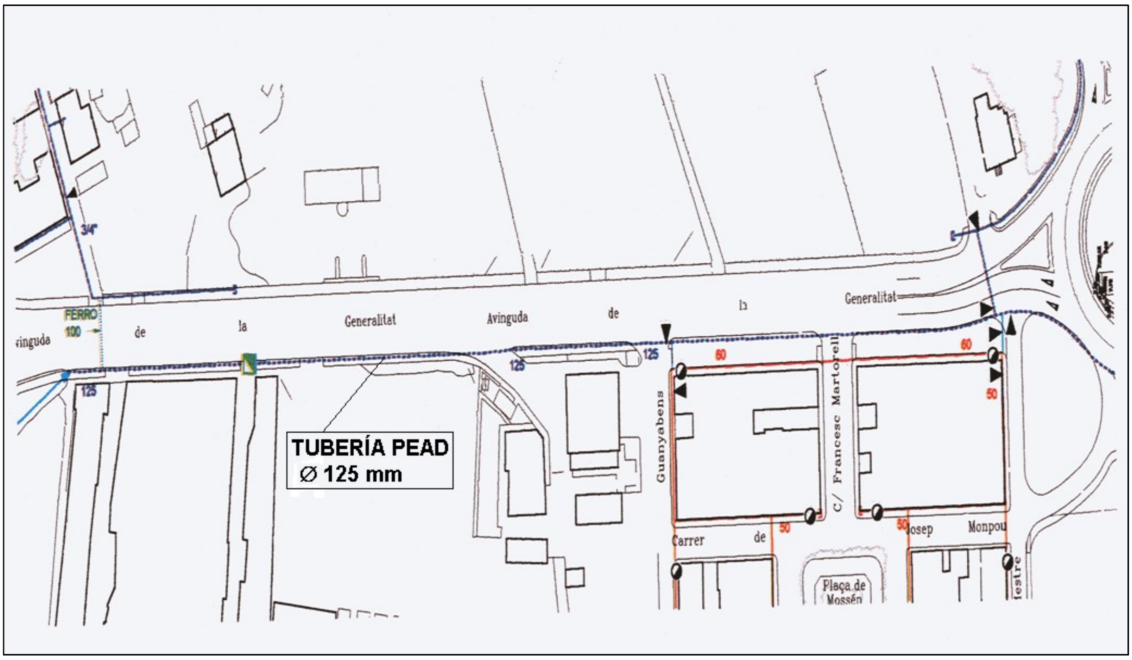

Figure 1. HDPE pipe (high-density polyethylene).

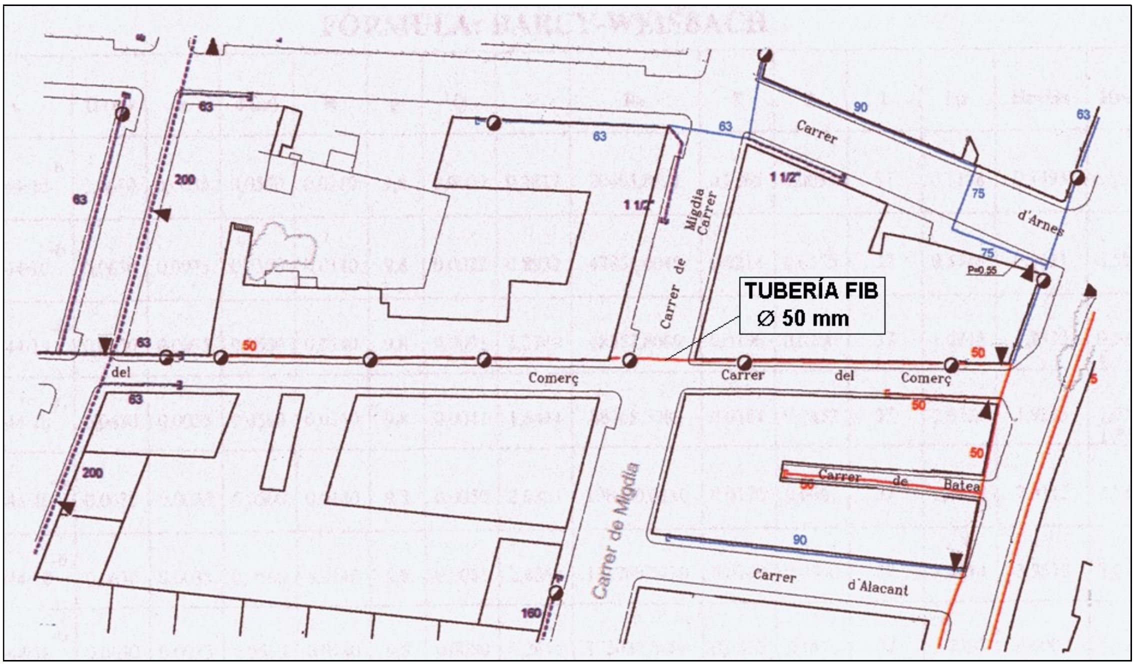

Figure 2. Asbestos cement piper.

A more exhaustive explanation of the materials and procedure used in this trial can be seen in "additional web material".

3.4.- RESULTS

Subsequently, the comparison of the results obtained according to the materials was carried out depending on the average of the difference between the theoretical pressure that is deduced from the different formulations (adding to the loss of continuous pressure 15% for losses singular load of the network) and the one actually obtained, for each of the three pipes under study. For this, the corresponding tables and graphs in number of 25 were prepared, a sample of which can be seen in table and graph 22 referring to the Manning-Strickler-Gaukler formulation for the HDPE pipe, resulting in the following:

a) PEAD:

- Darcy-Weisbach's formula = -3.2883
- Blasius-Flamant's formula = -3.2890
- Manning-Strickler's formula = -3.6326
- Kütter's formula = -1.1048
- Hazen-Williams formula = -3.0870
- Scobey's formula = -2.2102
- Franquet's formula = 1.121 (1.5276)

The formulas closest to the reality of our pipes, as can be verified, are that of Kütter and the one proposed here by Franquet, although one is by excess and the other by default.

b) PVC:

- Darcy-Weisbach's formula = 0.3757
- Blasius-Flamant's formula = 0.4418
- Manning-Strickler's formula = 0.7108
- Kütter's formula = 2.3454
- Hazen-Williams formula = 0.4358
- Scobey's formula = 0.7130
- Franquet's formula = 0.6860

In this case, the formula that is closest to the result obtained in practice is that of Darcy-Weisbach.

c) ASBESTOS CEMENT:

- Darcy-Weisbach's formula = -3.4635
- Scimemi's formula = -4.6413
- Blasius-Flamant's formula = 1.2562
- Manning-Strickler's formula = 12.0355
- Kütter's formula = 3.6701
- Hazen-Williams formula = 2.5505
- Scobey's formula = 3.2267
- Meyer-Peter's formula = 0.3240 (0.5685)
- Ludin's formula = -2.1607
- Stucky's formula = 2.9099
- Franquet's formula = 1.9583

In the latter case, the closest formula to the sampling is that of Meyer-Peter, which is a special formula for calculating asbestos cement pipes. Those of [15] and Franquet also offer good results. However, those of von Ludin, Scimemi and Stucky [16] are also special for asbestos cement, but do not give as good results, as can be seen.

Comparing the discrepancies of the values resulting from the application of the 7 previous formulas for the 3 pipes analyzed, in relation to the values actually obtained from the head losses, the joint results of table 23 are obtained.

Finally, to assess whether there are significant differences between the distribution of the values of the total pressure losses obtained by application of the 7 different formulas studied and the distribution actually measured, it is convenient to test the hypothesis at the significance level of the 0.10. In this regard, we recommend consulting Annex 3 of our book [6] regarding the “Chi-Square” statistical test (p. 562 and following).

In our case, the critical value of $\chi 2_{0.90}$ will take into account the number of categories or classes for each test (8 for PVC pipe, 7 for HDPE and 6 for asbestos cement), with one less unit for the number degrees of freedom (d.f.). That is:

$$\chi^2_{0.90}\ (7\ \text{d.f.}) = 12.0\ (\text{PVC}) \quad ; \chi^2_{0.10}\ (7\ \text{d.f.}) = 2.83\ (\text{PVC})$$

$$\chi^2_{0.90}\ (6\ \text{d.f.}) = 10.6\ (\text{HDPE}) \quad ; \chi^2_{0.10}\ (6\ \text{d.f.}) = 2.20\ (\text{HDPE})$$

$$\chi^2_{0.90}\ (5\ \text{d.f.}) = 9.24\ (\text{ASB}) \quad ; \chi^2_{0.10}\ (5\ \text{d.f.}) = 1.61\ (\text{ASB})$$

In any case, also the hypothesis test or test χ^2 fully confirms the goodness of the formulation proposed here for calculating pressure pipes.

4.- CONCLUSIONS

The consideration of 12 categories of roughness (K) of walls and screed in free conduits allows the calculation engineer to apply non-integer or intermediate values to this parameter between 2 correlative categories, with which the margin of maneuver is greatly expanded.

Already in the case of forced or pressure pipes, it is confirmed that the formulation proposed here is the one that offers the most confidence from the statistical point of view, comparing it with other 5 formulations of usual use in the hydraulic dimensioning of pipes and water distribution networks agricultural, industrial or urban, achieving, with sufficient and expressive clarity, better results than any of them.

Lastly, the results obtained from the experimental test carried out on three pipes made of polyethylene, polyvinyl chloride and asbestos cement show, once again, the goodness of the formulation proposed here for the calculation and dimensioning of forced pipes, since it is the one that offers the smallest discrepancies between the values observed in the test and the theoretical ones.

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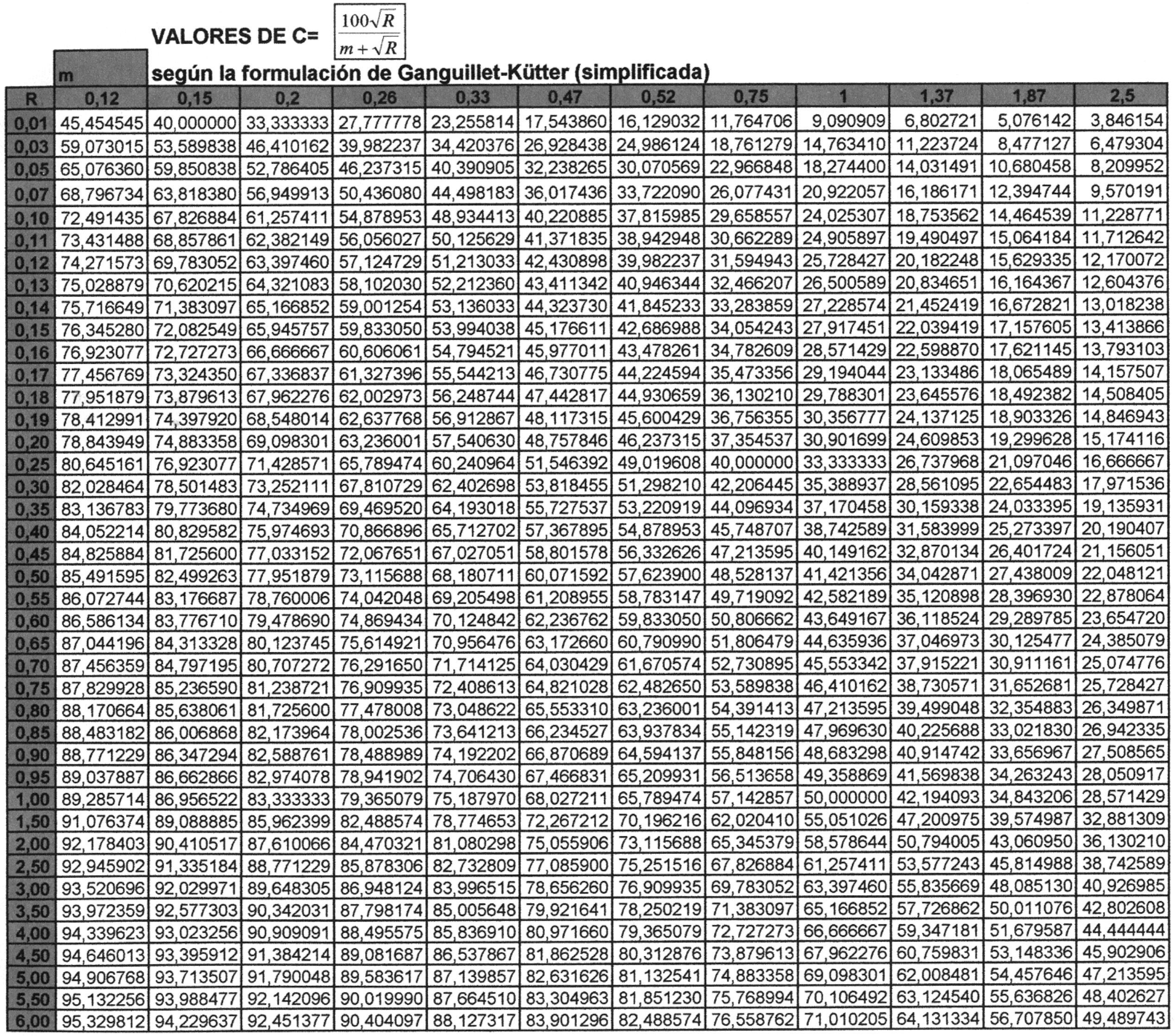
*Supplementary material in attached ANNEX.

ANNEX

NEW PROPOSED FORMULATIONS FOR THE CALCULATION OF HYDRAULIC CONDUCTIONS

(ADDITIONAL MATERIAL)



VALORES DE C= $\frac{100\sqrt{R}}{m+\sqrt{R}}$

según la formulación de Ganguillet-Kütter (simplificada)

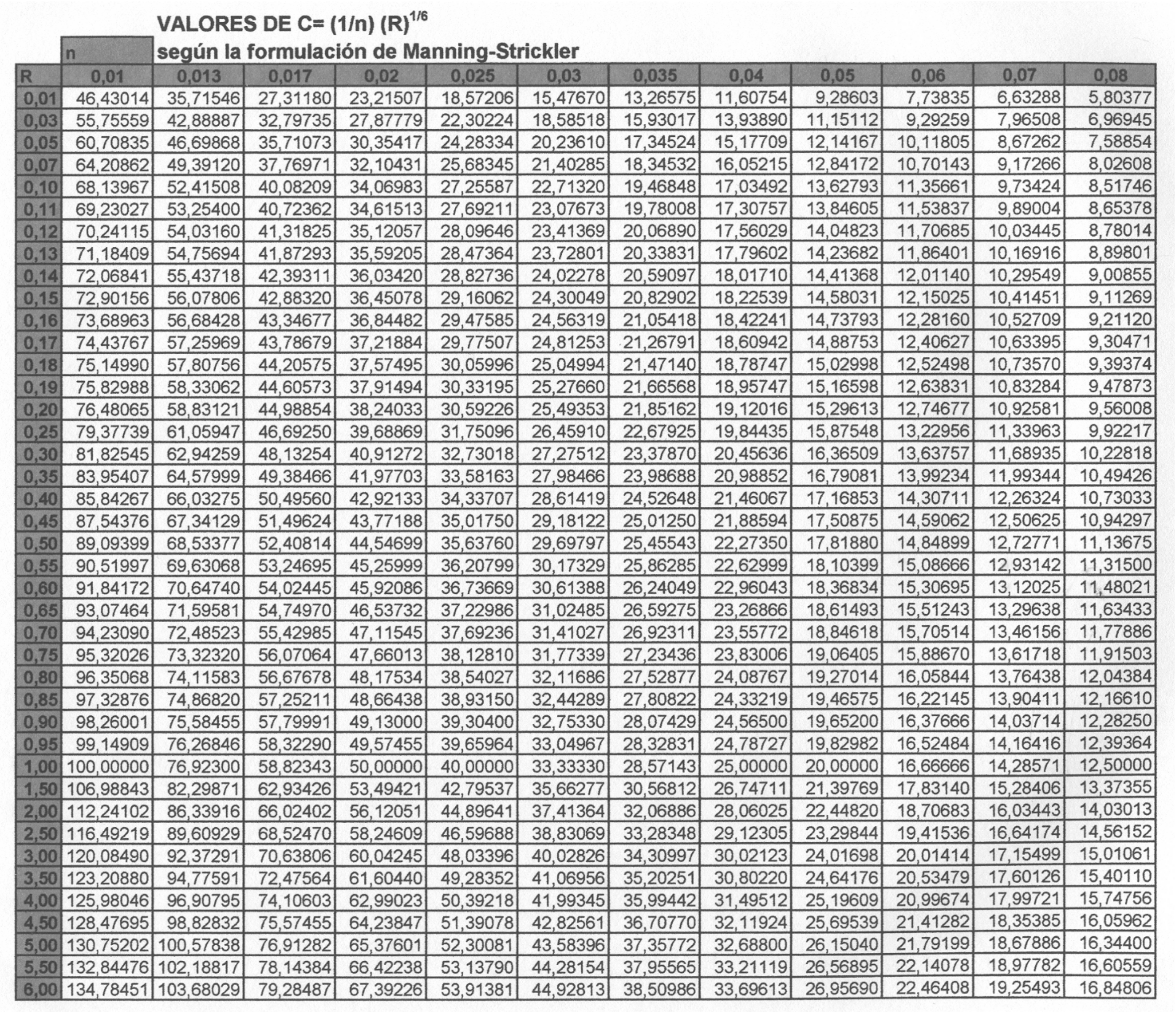
R \ m	0,12	0,15	0,2	0,26	0,33	0,47	0,52	0,75	1	1,37	1,87	2,5
0,01	45,454545	40,000000	33,333333	27,777778	23,255814	17,543860	16,129032	11,764706	9,090909	6,802721	5,076142	3,846154
0,03	59,073015	53,589838	46,410162	39,982237	34,420376	26,928438	24,986124	18,761279	14,763410	11,223724	8,477127	6,479304
0,05	65,076360	59,850838	52,786405	46,237315	40,390905	32,238265	30,070569	22,966848	18,274400	14,031491	10,680458	8,209952
0,07	68,796734	63,818380	56,949913	50,436080	44,498183	36,017436	33,722090	26,077431	20,922057	16,186171	12,394744	9,570191
0,10	72,491435	67,826884	61,257411	54,878953	48,934413	40,220885	37,815985	29,658557	24,025307	18,753562	14,464539	11,228771
0,11	73,431488	68,857861	62,382149	56,056027	50,125629	41,371835	38,942948	30,662289	24,905897	19,490497	15,064184	11,712642
0,12	74,271573	69,783052	63,397460	57,124729	51,213033	42,430898	39,982237	31,594943	25,728427	20,182248	15,629335	12,170072
0,13	75,028879	70,620215	64,321083	58,102030	52,212360	43,411342	40,946344	32,466207	26,500589	20,834651	16,164367	12,604376
0,14	75,716649	71,383097	65,166852	59,001254	53,136033	44,323730	41,845233	33,283859	27,228574	21,452419	16,672821	13,018238
0,15	76,345280	72,082549	65,945757	59,833050	53,994038	45,176611	42,686988	34,054243	27,917451	22,039419	17,157605	13,413866
0,16	76,923077	72,727273	66,666667	60,606061	54,794521	45,977011	43,478261	34,782609	28,571429	22,598870	17,621145	13,793103
0,17	77,456769	73,324350	67,336837	61,327396	55,544213	46,730775	44,224594	35,473356	29,194044	23,133486	18,065489	14,157507
0,18	77,951879	73,879613	67,962276	62,002973	56,248744	47,442817	44,930659	36,130210	29,788301	23,645576	18,492382	14,508405
0,19	78,412991	74,397920	68,548014	62,637768	56,912867	48,117315	45,600429	36,756355	30,356777	24,137125	18,903326	14,846943
0,20	78,843949	74,883358	69,098301	63,236001	57,540630	48,757846	46,237315	37,354537	30,901699	24,609853	19,299628	15,174116
0,25	80,645161	76,923077	71,428571	65,789474	60,240964	51,546392	49,019608	40,000000	33,333333	26,737968	21,097046	16,666667
0,30	82,028464	78,501483	73,252111	67,810729	62,402698	53,818455	51,298210	42,206445	35,388937	28,561095	22,654483	17,971536
0,35	83,136783	79,773680	74,734969	69,469520	64,193018	55,727537	53,220919	44,096934	37,170458	30,159338	24,033395	19,135931
0,40	84,052214	80,829582	75,974693	70,866896	65,712702	57,367895	54,878953	45,748707	38,742589	31,583999	25,273397	20,190407
0,45	84,825884	81,725600	77,033152	72,067651	67,027051	58,801578	56,332626	47,213595	40,149162	32,870134	26,401724	21,156051
0,50	85,491595	82,499263	77,951879	73,115688	68,180711	60,071592	57,623900	48,528137	41,421356	34,042871	27,438009	22,048121
0,55	86,072744	83,176687	78,760006	74,042048	69,205498	61,208955	58,783147	49,719092	42,582189	35,120898	28,396930	22,878064
0,60	86,586134	83,776710	79,478690	74,869434	70,124842	62,236762	59,833050	50,806662	43,649167	36,118524	29,289785	23,654720
0,65	87,044196	84,313328	80,123745	75,614921	70,956476	63,172660	60,790990	51,806479	44,635936	37,046973	30,125477	24,385079
0,70	87,456359	84,797195	80,707272	76,291650	71,714125	64,030429	61,670574	52,730895	45,553342	37,915221	30,911161	25,074776
0,75	87,829928	85,236590	81,238721	76,909935	72,408613	64,821028	62,482650	53,589838	46,410162	38,730571	31,652681	25,728427
0,80	88,170664	85,638061	81,725600	77,478008	73,048622	65,553310	63,236001	54,391413	47,213595	39,499048	32,354883	26,349871
0,85	88,483182	86,006868	82,173964	78,002536	73,641213	66,234527	63,937834	55,142319	47,969630	40,225688	33,021830	26,942335
0,90	88,771229	86,347294	82,588761	78,488989	74,192202	66,870689	64,594137	55,848156	48,683298	40,914742	33,656967	27,508565
0,95	89,037887	86,662866	82,974078	78,941902	74,706430	67,466831	65,209931	56,513658	49,358869	41,569838	34,263243	28,050917
1,00	89,285714	86,956522	83,333333	79,365079	75,187970	68,027211	65,789474	57,142857	50,000000	42,194093	34,843206	28,571429
1,50	91,076374	89,088885	85,962399	82,488574	78,774653	72,267212	70,196216	62,020410	55,051026	47,200975	39,574987	32,881309
2,00	92,178403	90,410517	87,610066	84,470321	81,080298	75,055906	73,115688	65,345379	58,578644	50,794005	43,060950	36,130210
2,50	92,945902	91,335184	88,771229	85,878306	82,732809	77,085900	75,251516	67,826884	61,257411	53,577243	45,814988	38,742589
3,00	93,520696	92,029971	89,648305	86,948124	83,996515	78,656260	76,909935	69,783052	63,397460	55,835669	48,085130	40,926985
3,50	93,972359	92,577303	90,342031	87,798174	85,005648	79,921641	78,250219	71,383097	65,166852	57,726862	50,011076	42,802608
4,00	94,339623	93,023256	90,909091	88,495575	85,836910	80,971660	79,365079	72,727273	66,666667	59,347181	51,679587	44,444444
4,50	94,646013	93,395912	91,384214	89,081687	86,537867	81,862528	80,312876	73,879613	67,962276	60,759831	53,148336	45,902906
5,00	94,906768	93,713507	91,790048	89,583617	87,139857	82,631626	81,132541	74,883358	69,098301	62,008481	54,457646	47,213595
5,50	95,132256	93,988477	92,142096	90,019990	87,664510	83,304963	81,851230	75,768994	70,106492	63,124540	55,636826	48,402627
6,00	95,329812	94,229637	92,451377	90,404097	88,127317	83,901296	82,488574	76,558762	71,010205	64,131334	56,707850	49,489743

Table 1. Ganguillet-Kütter formulation (simplified). Values of C.

Valores del coeficiente de Fanning (λ), en conducciones libres, según la fórmula simplificada de Ganguillet y Kütter

	m										
R	**0,12**	**0,15**	**0,2**	**0,26**	**0,33**	**0,47**	**0,52**	**0,75**	**1**	**1,37**	**1,87**	**2,5**
0,01	0,0094864	0,0122500	0,0176400	0,0254016	0,0362404	0,0636804	0,0753424	0,1416100	0,2371600	0,4235364	0,7606564	1,3249600
0,03	0,0056167	0,0068248	0,0090998	0,0122609	0,0165434	0,0270292	0,0313948	0,0556841	0,0899255	0,1555902	0,2727462	0,4668737
0,05	0,0046282	0,0054716	0,0070342	0,0091679	0,0120140	0,0188587	0,0216757	0,0371581	0,0586908	0,0995516	0,1718210	0,2907869
0,07	0,0041411	0,0048124	0,0060432	0,0077050	0,0098985	0,0151088	0,0172356	0,0288222	0,0447762	0,0748114	0,1275795	0,2140005
0,10	0,0037298	0,0042604	0,0052232	0,0065080	0,0081852	0,0121158	0,0137058	0,0222821	0,0339561	0,0557299	0,0936800	0,1554503
0,11	0,0036349	0,0041338	0,0050366	0,0062375	0,0078008	0,0114511	0,0129240	0,0208472	0,0315974	0,0515953	0,0863704	0,1428717
0,12	0,0035531	0,0040249	0,0048765	0,0060063	0,0074730	0,0108866	0,0122609	0,0196345	0,0296094	0,0481190	0,0802371	0,1323335
0,13	0,0034818	0,0039300	0,0047375	0,0058060	0,0071897	0,0104004	0,0116903	0,0185949	0,0279090	0,0451527	0,0750134	0,1233711
0,14	0,0034188	0,0038465	0,0046153	0,0056303	0,0069419	0,0099766	0,0111935	0,0176925	0,0264366	0,0425896	0,0705079	0,1156516
0,15	0,0033627	0,0037722	0,0045069	0,0054749	0,0067230	0,0096035	0,0107564	0,0169010	0,0251481	0,0403511	0,0665798	0,1089302
0,16	0,0033124	0,0037056	0,0044100	0,0053361	0,0065280	0,0092720	0,0103684	0,0162006	0,0240100	0,0383780	0,0631230	0,1030225
0,17	0,0032669	0,0036455	0,0043227	0,0052113	0,0063530	0,0089753	0,0100214	0,0155758	0,0229968	0,0366247	0,0600560	0,0977873
0,18	0,0032255	0,0035909	0,0042435	0,0050984	0,0061948	0,0087079	0,0097089	0,0150146	0,0220884	0,0350555	0,0573153	0,0931144
0,19	0,0031877	0,0035411	0,0041713	0,0049956	0,0060511	0,0084655	0,0094258	0,0145075	0,0212689	0,0336422	0,0548504	0,0889164
0,20	0,0031530	0,0034953	0,0041051	0,0049015	0,0059198	0,0082446	0,0091679	0,0140465	0,0205254	0,0323622	0,0526209	0,0851235
0,25	0,0030137	0,0033124	0,0038416	0,0045284	0,0054010	0,0073767	0,0081567	0,0122500	0,0176400	0,0274157	0,0440365	0,0705600
0,30	0,0029129	0,0031805	0,0036527	0,0042624	0,0050333	0,0067670	0,0074482	0,0110027	0,0156502	0,0240274	0,0381898	0,0606856
0,35	0,0028358	0,0030799	0,0035092	0,0040613	0,0047564	0,0063113	0,0069198	0,0100795	0,0141860	0,0215483	0,0339333	0,0535250
0,40	0,0027743	0,0030000	0,0033956	0,0039027	0,0045390	0,0059555	0,0065080	0,0093648	0,0130581	0,0196482	0,0306852	0,0480802
0,45	0,0027240	0,0029345	0,0033029	0,0037738	0,0043627	0,0056686	0,0061764	0,0087927	0,0121591	0,0181407	0,0281185	0,0437912
0,50	0,0026817	0,0028798	0,0032255	0,0036664	0,0042163	0,0054315	0,0059027	0,0083228	0,0114237	0,0169123	0,0260346	0,0403193
0,55	0,0026456	0,0028330	0,0031597	0,0035752	0,0040924	0,0052315	0,0056722	0,0079288	0,0108094	0,0158900	0,0243060	0,0374470
0,60	0,0026143	0,0027926	0,0031028	0,0034966	0,0039858	0,0050601	0,0054749	0,0075930	0,0102874	0,0150244	0,0228467	0,0350284
0,65	0,0025869	0,0027572	0,0030530	0,0034280	0,0038929	0,0049113	0,0053037	0,0073028	0,0098375	0,0142807	0,0215967	0,0329616
0,70	0,0025626	0,0027258	0,0030091	0,0033675	0,0038111	0,0047806	0,0051535	0,0070490	0,0094453	0,0136342	0,0205128	0,0311732
0,75	0,0025408	0,0026978	0,0029698	0,0033135	0,0037383	0,0046647	0,0050204	0,0068248	0,0090998	0,0130662	0,0195630	0,0296094
0,80	0,0025212	0,0026725	0,0029345	0,0032651	0,0036731	0,0045611	0,0049015	0,0066251	0,0087927	0,0125627	0,0187230	0,0282292
0,85	0,0025034	0,0026497	0,0029026	0,0032214	0,0036142	0,0044677	0,0047945	0,0064459	0,0085177	0,0121129	0,0179744	0,0270014
0,90	0,0024872	0,0026288	0,0028735	0,0031815	0,0035607	0,0043831	0,0046975	0,0062840	0,0082698	0,0117084	0,0173024	0,0259012
0,95	0,0024723	0,0026097	0,0028469	0,0031451	0,0035119	0,0043060	0,0046092	0,0061369	0,0080450	0,0113423	0,0166955	0,0249093
1,00	0,0024586	0,0025921	0,0028224	0,0031117	0,0034670	0,0042354	0,0045284	0,0060025	0,0078400	0,0110091	0,0161443	0,0240100
1,50	0,0023629	0,0024695	0,0026524	0,0028805	0,0031585	0,0037530	0,0039777	0,0050955	0,0064673	0,0087974	0,0125145	0,0181283
2,00	0,0023067	0,0023978	0,0025536	0,0027469	0,0029814	0,0034793	0,0036664	0,0045901	0,0057119	0,0075968	0,0105703	0,0150146
2,50	0,0022688	0,0023495	0,0024872	0,0026576	0,0028635	0,0032984	0,0034612	0,0042604	0,0052232	0,0068280	0,0093377	0,0130581
3,00	0,0022410	0,0023142	0,0024388	0,0025926	0,0027780	0,0031680	0,0033135	0,0040249	0,0048765	0,0062868	0,0084768	0,0117014
3,50	0,0022195	0,0022869	0,0024015	0,0025426	0,0027124	0,0030685	0,0032010	0,0038465	0,0046153	0,0058817	0,0078365	0,0106983
4,00	0,0022023	0,0022650	0,0023716	0,0025027	0,0026602	0,0029894	0,0031117	0,0037056	0,0044100	0,0055649	0,0073387	0,0099225
4,50	0,0021880	0,0022470	0,0023470	0,0024699	0,0026172	0,0029247	0,0030387	0,0035909	0,0042435	0,0053091	0,0069387	0,0093020
5,00	0,0021760	0,0022318	0,0023263	0,0024423	0,0025812	0,0028705	0,0029776	0,0034953	0,0041051	0,0050975	0,0066090	0,0087927
5,50	0,0021657	0,0022187	0,0023086	0,0024187	0,0025504	0,0028243	0,0029255	0,0034141	0,0039879	0,0049188	0,0063319	0,0083660
6,00	0,0021567	0,0022074	0,0022931	0,0023982	0,0025237	0,0027843	0,0028805	0,0033440	0,0038870	0,0047656	0,0060949	0,0080025

Table 2. Ganguillet-Kütter formulation (simplified). Values of λ.



VALORES DE C= (1/n) $(R)^{1/6}$

según la formulación de Manning-Strickler

	n											
R	0,01	0,013	0,017	0,02	0,025	0,03	0,035	0,04	0,05	0,06	0,07	0,08
0,01	46,43014	35,71546	27,31180	23,21507	18,57206	15,47670	13,26575	11,60754	9,28603	7,73835	6,63288	5,80377
0,03	55,75559	42,88887	32,79735	27,87779	22,30224	18,58518	15,93017	13,93890	11,15112	9,29259	7,96508	6,96945
0,05	60,70835	46,69868	35,71073	30,35417	24,28334	20,23610	17,34524	15,17709	12,14167	10,11805	8,67262	7,58854
0,07	64,20862	49,39120	37,76971	32,10431	25,68345	21,40285	18,34532	16,05215	12,84172	10,70143	9,17266	8,02608
0,10	68,13967	52,41508	40,08209	34,06983	27,25587	22,71320	19,46848	17,03492	13,62793	11,35661	9,73424	8,51746
0,11	69,23027	53,25400	40,72362	34,61513	27,69211	23,07673	19,78008	17,30757	13,84605	11,53837	9,89004	8,65378
0,12	70,24115	54,03160	41,31825	35,12057	28,09646	23,41369	20,06890	17,56029	14,04823	11,70685	10,03445	8,78014
0,13	71,18409	54,75694	41,87293	35,59205	28,47364	23,72801	20,33831	17,79602	14,23682	11,86401	10,16916	8,89801
0,14	72,06841	55,43718	42,39311	36,03420	28,82736	24,02278	20,59097	18,01710	14,41368	12,01140	10,29549	9,00855
0,15	72,90156	56,07806	42,88320	36,45078	29,16062	24,30049	20,82902	18,22539	14,58031	12,15025	10,41451	9,11269
0,16	73,68963	56,68428	43,34677	36,84482	29,47585	24,56319	21,05418	18,42241	14,73793	12,28160	10,52709	9,21120
0,17	74,43767	57,25969	43,78679	37,21884	29,77507	24,81253	21,26791	18,60942	14,88753	12,40627	10,63395	9,30471
0,18	75,14990	57,80756	44,20575	37,57495	30,05996	25,04994	21,47140	18,78747	15,02998	12,52498	10,73570	9,39374
0,19	75,82988	58,33062	44,60573	37,91494	30,33195	25,27660	21,66568	18,95747	15,16598	12,63831	10,83284	9,47873
0,20	76,48065	58,83121	44,98854	38,24033	30,59226	25,49353	21,85162	19,12016	15,29613	12,74677	10,92581	9,56008
0,25	79,37739	61,05947	46,69250	39,68869	31,75096	26,45910	22,67925	19,84435	15,87548	13,22956	11,33963	9,92217
0,30	81,82545	62,94259	48,13254	40,91272	32,73018	27,27512	23,37870	20,45636	16,36509	13,63757	11,68935	10,22818
0,35	83,95407	64,57999	49,38466	41,97703	33,58163	27,98466	23,98688	20,98852	16,79081	13,99234	11,99344	10,49426
0,40	85,84267	66,03275	50,49560	42,92133	34,33707	28,61419	24,52648	21,46067	17,16853	14,30711	12,26324	10,73033
0,45	87,54376	67,34129	51,49624	43,77188	35,01750	29,18122	25,01250	21,88594	17,50875	14,59062	12,50625	10,94297
0,50	89,09399	68,53377	52,40814	44,54699	35,63760	29,69797	25,45543	22,27350	17,81880	14,84899	12,72771	11,13675
0,55	90,51997	69,63068	53,24695	45,25999	36,20799	30,17329	25,86285	22,62999	18,10399	15,08666	12,93142	11,31500
0,60	91,84172	70,64740	54,02445	45,92086	36,73669	30,61388	26,24049	22,96043	18,36834	15,30695	13,12025	11,48021
0,65	93,07464	71,59581	54,74970	46,53732	37,22986	31,02485	26,59275	23,26866	18,61493	15,51243	13,29638	11,63433
0,70	94,23090	72,48523	55,42985	47,11545	37,69236	31,41027	26,92311	23,55772	18,84618	15,70514	13,46156	11,77886
0,75	95,32026	73,32320	56,07064	47,66013	38,12810	31,77339	27,23436	23,83006	19,06405	15,88670	13,61718	11,91503
0,80	96,35068	74,11583	56,67678	48,17534	38,54027	32,11686	27,52877	24,08767	19,27014	16,05844	13,76438	12,04384
0,85	97,32876	74,86820	57,25211	48,66438	38,93150	32,44289	27,80822	24,33219	19,46575	16,22145	13,90411	12,16610
0,90	98,26001	75,58455	57,79991	49,13000	39,30400	32,75330	28,07429	24,56500	19,65200	16,37666	14,03714	12,28250
0,95	99,14909	76,26846	58,32290	49,57455	39,65964	33,04967	28,32831	24,78727	19,82982	16,52484	14,16416	12,39364
1,00	100,00000	76,92300	58,82343	50,00000	40,00000	33,33330	28,57143	25,00000	20,00000	16,66666	14,28571	12,50000
1,50	106,98843	82,29871	62,93426	53,49421	42,79537	35,66277	30,56812	26,74711	21,39769	17,83140	15,28406	13,37355
2,00	112,24102	86,33916	66,02402	56,12051	44,89641	37,41364	32,06886	28,06025	22,44820	18,70683	16,03443	14,03013
2,50	116,49219	89,60929	68,52470	58,24609	46,59688	38,83069	33,28348	29,12305	23,29844	19,41536	16,64174	14,56152
3,00	120,08490	92,37291	70,63806	60,04245	48,03396	40,02826	34,30997	30,02123	24,01698	20,01414	17,15499	15,01061
3,50	123,20880	94,77591	72,47564	61,60440	49,28352	41,06956	35,20251	30,80220	24,64176	20,53479	17,60126	15,40110
4,00	125,98046	96,90795	74,10603	62,99023	50,39218	41,99345	35,99442	31,49512	25,19609	20,99674	17,99721	15,74756
4,50	128,47695	98,82832	75,57455	64,23847	51,39078	42,82561	36,70770	32,11924	25,69539	21,41282	18,35385	16,05962
5,00	130,75202	100,57838	76,91282	65,37601	52,30081	43,58396	37,35772	32,68800	26,15040	21,79199	18,67886	16,34400
5,50	132,84476	102,18817	78,14384	66,42238	53,13790	44,28154	37,95565	33,21119	26,56895	22,14078	18,97782	16,60559
6,00	134,78451	103,68029	79,28487	67,39226	53,91381	44,92813	38,50986	33,69613	26,95690	22,46408	19,25493	16,84806

Table 3. Manning-Strickler formulation (simplified). Values of C.

Coeficiente de Fanning $(\lambda = 2g/C^2)$

según la formulación de Manning-Strickler

	n											
R	**0,01**	**0,013**	**0,017**	**0,02**	**0,025**	**0,03**	**0,035**	**0,04**	**0,05**	**0,06**	**0,07**	**0,08**
0,01	0,0090919	0,0153654	0,0262758	0,0363677	0,0568246	0,0818275	0,1113761	0,1454709	0,2272982	0,3273097	0,4455046	0,5818835
0,03	0,0063049	0,0106553	0,0182213	0,0252197	0,0394057	0,0567444	0,0772352	0,1008786	0,1576229	0,2269771	0,3089409	0,4035146
0,05	0,0053181	0,0089877	0,0153695	0,0212725	0,0332383	0,0478633	0,0651471	0,0850901	0,1329533	0,1914530	0,2605886	0,3403606
0,07	0,0047541	0,0080345	0,0137394	0,0190164	0,0297132	0,0427871	0,0582379	0,0760658	0,1188528	0,1711482	0,2329515	0,3042632
0,10	0,0042214	0,0071342	0,0121999	0,0168856	0,0263837	0,0379926	0,0517121	0,0675423	0,1055349	0,1519704	0,2068484	0,2701693
0,11	0,0040894	0,0069112	0,0118185	0,0163578	0,0255590	0,0368050	0,0500957	0,0654311	0,1022360	0,1472200	0,2003826	0,2617243
0,12	0,0039726	0,0067137	0,0114808	0,0158903	0,0248286	0,0357533	0,0486641	0,0635613	0,0993146	0,1430131	0,1946565	0,2542453
0,13	0,0038680	0,0065370	0,0111787	0,0154721	0,0241752	0,0348124	0,0473834	0,0618885	0,0967008	0,1392493	0,1895336	0,2475541
0,14	0,0037737	0,0063775	0,0109060	0,0150948	0,0235856	0,0339633	0,0462277	0,0603790	0,0943422	0,1358529	0,1849108	0,2415162
0,15	0,0036879	0,0062326	0,0106581	0,0147517	0,0230496	0,0331914	0,0451771	0,0590069	0,0921982	0,1327655	0,1807085	0,2360274
0,16	0,0036095	0,0061000	0,0104314	0,0144379	0,0225592	0,0324853	0,0442160	0,0577515	0,0902367	0,1299410	0,1768640	0,2310060
0,17	0,0035373	0,0059780	0,0102228	0,0141492	0,0221081	0,0318357	0,0433318	0,0565966	0,0884322	0,1273425	0,1733271	0,2263865
0,18	0,0034706	0,0058653	0,0100299	0,0138822	0,0216910	0,0312351	0,0425143	0,0555289	0,0867639	0,1249402	0,1700573	0,2221157
0,19	0,0034086	0,0057605	0,0098509	0,0136344	0,0213037	0,0306774	0,0417553	0,0545375	0,0852149	0,1227095	0,1670211	0,2181501
0,20	0,0033508	0,0056629	0,0096839	0,0134033	0,0209427	0,0301576	0,0410477	0,0536133	0,0837708	0,1206301	0,1641909	0,2144534
0,25	0,0031107	0,0052571	0,0089900	0,0124429	0,0194421	0,0279966	0,0381065	0,0497717	0,0777683	0,1119864	0,1524258	0,1990868
0,30	0,0029274	0,0049473	0,0084602	0,0117095	0,0182961	0,0263465	0,0358604	0,0468381	0,0731845	0,1053858	0,1434417	0,1873524
0,35	0,0027808	0,0046996	0,0080366	0,0111233	0,0173801	0,0250274	0,0340650	0,0444931	0,0695205	0,1001095	0,1362601	0,1779724
0,40	0,0026598	0,0044951	0,0076869	0,0106392	0,0166238	0,0239383	0,0325826	0,0425569	0,0664951	0,0957530	0,1303304	0,1702275
0,45	0,0025574	0,0043221	0,0073910	0,0102298	0,0159840	0,0230170	0,0313287	0,0409191	0,0639360	0,0920680	0,1253146	0,1636762
0,50	0,0024692	0,0041730	0,0071361	0,0098769	0,0154326	0,0222230	0,0302479	0,0395075	0,0617304	0,0888919	0,1209916	0,1580299
0,55	0,0023920	0,0040425	0,0069130	0,0095681	0,0149502	0,0215283	0,0293024	0,0382725	0,0598008	0,0861133	0,1172096	0,1530901
0,60	0,0023237	0,0039270	0,0067155	0,0092947	0,0145230	0,0209132	0,0284651	0,0371789	0,0580920	0,0836525	0,1138603	0,1487154
0,65	0,0022625	0,0038237	0,0065387	0,0090501	0,0141408	0,0203628	0,0277159	0,0362004	0,0565631	0,0814510	0,1108637	0,1448016
0,70	0,0022073	0,0037304	0,0063792	0,0088294	0,0137959	0,0198661	0,0270399	0,0353175	0,0551835	0,0794643	0,1081597	0,1412698
0,75	0,0021572	0,0036456	0,0062343	0,0086287	0,0134824	0,0194146	0,0264254	0,0345148	0,0539294	0,0776584	0,1057016	0,1380593
0,80	0,0021113	0,0035681	0,0061016	0,0084451	0,0131955	0,0190016	0,0258632	0,0337805	0,0527821	0,0760063	0,1034529	0,1351221
0,85	0,0020691	0,0034967	0,0059796	0,0082763	0,0129316	0,0186216	0,0253460	0,0331050	0,0517266	0,0744863	0,1013841	0,1324200
0,90	0,0020300	0,0034308	0,0058668	0,0081201	0,0126877	0,0182703	0,0248679	0,0324805	0,0507508	0,0730811	0,0994715	0,1299219
0,95	0,0019938	0,0033695	0,0057621	0,0079751	0,0124612	0,0179441	0,0244239	0,0319006	0,0498447	0,0717764	0,0976955	0,1276023
1,00	0,0019600	0,0033124	0,0056644	0,0078400	0,0122500	0,0176400	0,0240100	0,0313600	0,0490000	0,0705601	0,0960400	0,1254400
1,50	0,0017123	0,0028938	0,0049486	0,0068492	0,0107019	0,0154108	0,0209758	0,0273970	0,0428078	0,0616432	0,0839032	0,1095879
2,00	0,0015558	0,0026293	0,0044963	0,0062232	0,0097237	0,0140022	0,0190585	0,0248927	0,0388949	0,0560087	0,0762340	0,0995710
2,50	0,0014443	0,0024409	0,0041741	0,0057773	0,0090270	0,0129989	0,0176929	0,0231091	0,0361079	0,0519954	0,0707715	0,0924363
3,00	0,0013592	0,0022970	0,0039281	0,0054367	0,0084949	0,0122327	0,0166500	0,0217470	0,0339797	0,0489308	0,0666002	0,0869880
3,50	0,0012911	0,0021820	0,0037314	0,0051646	0,0080696	0,0116203	0,0158164	0,0206582	0,0322784	0,0464810	0,0632658	0,0826328
4,00	0,0012350	0,0020871	0,0035690	0,0049398	0,0077184	0,0111146	0,0151281	0,0197592	0,0308738	0,0444583	0,0605126	0,0790369
4,50	0,0011874	0,0020067	0,0034317	0,0047497	0,0074214	0,0106868	0,0145459	0,0189988	0,0296856	0,0427473	0,0581838	0,0759951
5,00	0,0011465	0,0019375	0,0033133	0,0045858	0,0071654	0,0103182	0,0140441	0,0183434	0,0286615	0,0412726	0,0561766	0,0733735
5,50	0,0011106	0,0018770	0,0032097	0,0044425	0,0069414	0,0099956	0,0136051	0,0177700	0,0277656	0,0399825	0,0544206	0,0710800
6,00	0,0010789	0,0018233	0,0031180	0,0043155	0,0067430	0,0097100	0,0132164	0,0172622	0,0269722	0,0388400	0,0528655	0,0690488

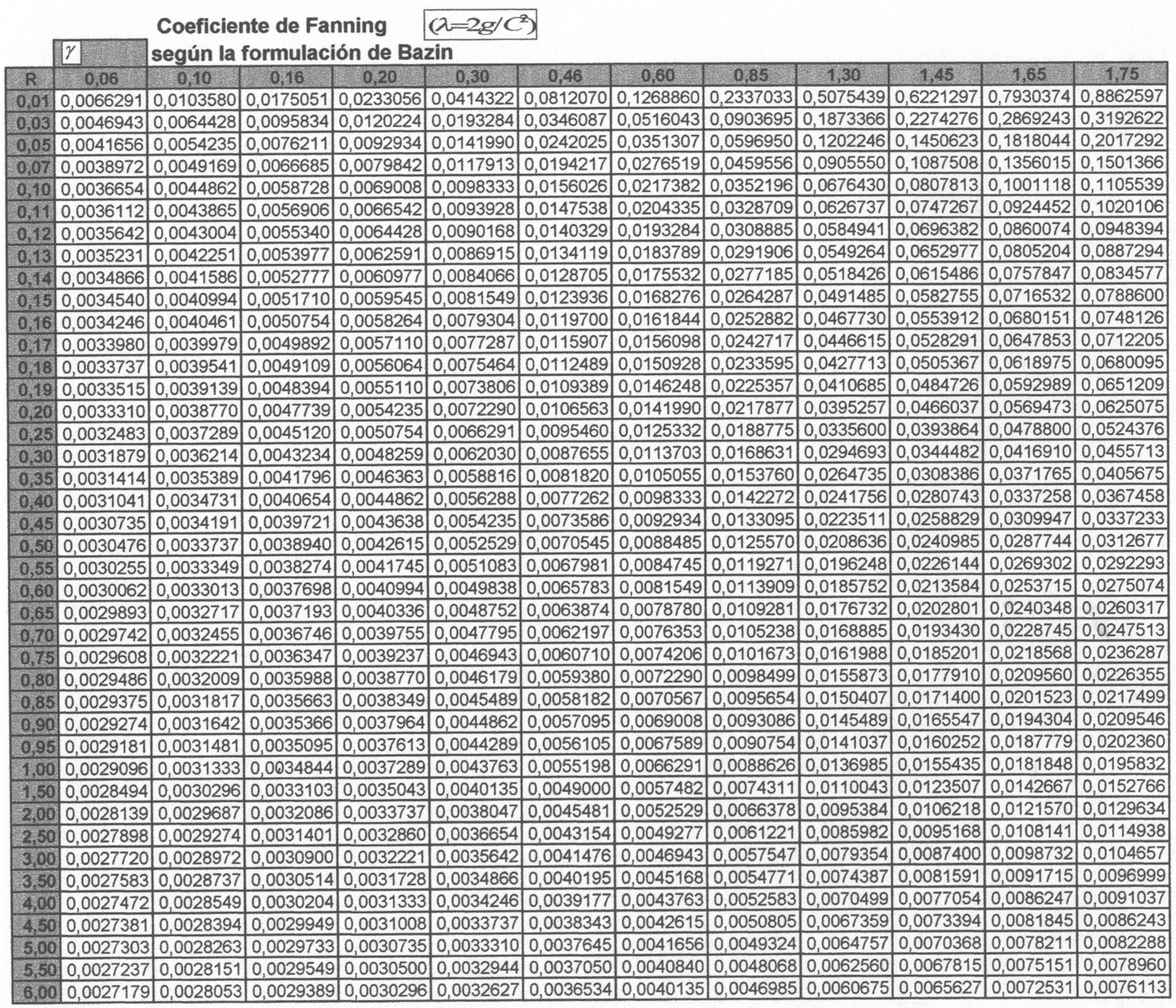
Table 4. Manning-Strickler formulation (simplified). Values of λ*.*

VALORES DE C= $87/(1+\frac{\gamma}{\sqrt{R}})$

γ **según la formulación de Bazin**

R	0,06	0,10	0,16	0,20	0,30	0,46	0,60	0,85	1,30	1,45	1,65	1,75
0,01	54,37500	43,50000	33,46154	29,00000	21,75000	15,53571	12,42857	9,15789	6,21429	5,61290	4,97143	4,70270
0,03	64,61627	55,15579	45,22393	40,37684	31,84421	23,79773	19,48880	14,72710	10,22861	9,28339	8,26503	7,83528
0,05	68,59424	60,11552	50,71284	45,92417	37,15344	28,45757	23,62024	18,12003	12,76825	11,62387	10,38307	9,85697
0,07	70,91744	63,13661	54,21428	49,54642	40,77055	31,76763	26,62352	20,65185	14,71200	13,42492	12,02253	11,42575
0,10	73,12543	66,09798	57,77029	53,29395	44,64553	35,44297	30,02727	23,59043	17,02224	15,57660	13,99218	13,31500
0,11	73,67220	66,84536	58,68789	54,27247	45,68046	36,44815	30,97113	24,41868	17,68419	16,19534	14,56082	13,86134
0,12	74,15583	67,51120	59,51240	55,15579	46,62316	37,37265	31,84421	25,19009	18,30509	16,77662	15,09594	14,37585
0,13	74,58783	68,10975	60,25932	55,95934	47,48778	38,22814	32,65642	25,91232	18,89025	17,32524	15,60181	14,86258
0,14	74,97694	68,65199	60,94067	56,69516	48,28548	39,02392	33,41569	26,59151	19,44396	17,84510	16,08189	15,32480
0,15	75,32994	69,14646	61,56597	57,37281	49,02522	39,76752	34,12844	27,23268	19,96977	18,33940	16,53904	15,76521
0,16	75,65217	69,60000	62,14286	58,00000	49,71429	40,46512	34,80000	27,84000	20,47059	18,81081	16,97561	16,18605
0,17	75,94795	70,01811	62,67754	58,58305	50,35868	41,12184	35,43480	28,41695	20,94890	19,26157	17,39361	16,58921
0,18	76,22076	70,40531	63,17516	59,12718	50,96342	41,74203	36,03658	28,96650	21,40680	19,69358	17,79473	16,97631
0,19	76,47347	70,76532	63,63998	59,63677	51,53274	42,32933	36,60854	29,49119	21,84610	20,10850	18,18045	17,34873
0,20	76,70848	71,10127	64,07561	60,11552	52,07023	42,88690	37,15344	29,99320	22,26836	20,50775	18,55204	17,70769
0,25	77,67857	72,50000	65,90909	62,14286	54,37500	45,31250	39,54545	32,22222	24,16667	22,30769	20,23256	19,33333
0,30	78,41055	73,56832	67,33128	63,72934	56,21162	47,28669	41,51863	34,09250	25,78951	23,85309	21,68238	20,73874
0,35	78,98905	74,42062	68,47971	65,01942	57,72705	48,94399	43,19365	35,70311	27,20960	25,21047	22,96115	21,98058
0,40	79,46161	75,12215	69,43435	66,09798	59,00939	50,36693	44,64553	37,11655	28,47343	26,42248	24,10721	23,09534
0,45	79,85734	75,71332	70,24548	67,01884	60,11552	51,60976	45,92417	38,37493	29,61273	27,51830	25,14687	24,10810
0,50	80,19521	76,22076	70,94661	67,81813	61,08418	52,71008	47,06447	39,50807	30,65023	28,51889	26,09907	25,03688
0,55	80,48819	76,66279	71,56112	68,52121	61,94287	53,69496	48,09181	40,53790	31,60281	29,43984	26,97792	25,89517
0,60	80,74548	77,05256	72,10587	69,14646	62,71182	54,58456	49,02522	41,48101	32,48338	30,29309	27,79428	26,69334
0,65	80,97386	77,39974	72,59343	69,70766	63,40626	55,39426	49,87936	42,35029	33,30205	31,08804	28,55668	27,43953
0,70	81,17840	77,71168	73,03335	70,21533	64,03799	56,13609	50,66573	43,15595	34,06692	31,83220	29,27196	28,14031
0,75	81,36301	77,99403	73,43308	70,67769	64,61627	56,81958	51,39352	43,90623	34,78455	32,53169	29,94573	28,80102
0,80	81,53075	78,25124	73,79852	71,10127	65,14852	57,45245	52,07023	44,60786	35,46035	33,19155	30,58259	29,42609
0,85	81,68407	78,48690	74,13439	71,49135	65,64077	58,04101	52,70200	45,26642	36,09887	33,81601	31,18641	30,01924
0,90	81,82494	78,70388	74,44457	71,85222	66,09798	58,59049	53,29395	45,88659	36,70390	34,40865	31,76049	30,58360
0,95	81,95496	78,90456	74,73222	72,18745	66,52426	59,10527	53,85040	46,47233	37,27871	34,97250	32,30761	31,12187
1,00	82,07547	79,09091	75,00000	72,50000	66,92308	59,58904	54,37500	47,02703	37,82609	35,51020	32,83019	31,63636
1,50	82,93694	80,43270	76,94761	74,78729	69,88238	63,24566	58,39326	51,35706	42,20339	39,83662	37,06513	35,81914
2,00	83,45913	81,25444	78,15749	76,22076	71,77436	65,64704	61,08418	54,33965	45,33047	42,95650	40,15274	38,88378
2,50	83,81928	81,82494	79,00523	77,23097	73,12543	67,39330	63,06755	56,58216	47,74469	45,38198	42,57294	41,29491
3,00	84,08714	82,25122	79,64290	77,99403	74,15583	68,74312	64,61627	58,35997	49,69851	47,35576	44,55534	43,27577
3,50	84,29650	82,58561	80,14566	78,59757	74,97694	69,83014	65,87348	59,82078	51,33109	49,01249	46,22835	44,95161
4,00	84,46602	82,85714	80,55556	79,09091	75,65217	70,73171	66,92308	61,05263	52,72727	50,43478	47,67123	46,40000
4,50	84,60695	83,08341	80,89827	79,50427	76,22076	71,49631	67,81813	62,11207	53,94259	51,67693	48,93641	47,67233
5,00	84,72655	83,27579	81,19048	79,85734	76,70848	72,15616	68,59424	63,03747	55,01532	52,77654	50,06035	48,80446
5,50	84,82971	83,44202	81,44357	80,16362	77,13310	72,73368	69,27629	63,85597	55,97296	53,76071	51,06945	49,82240
6,00	84,91990	83,58755	81,66562	80,43270	77,50733	73,24501	69,88238	64,58744	56,83590	54,64961	51,98345	50,74560

Table 5. Bazin formulation (simplified). Values of C.



Coeficiente de Fanning $(\lambda = 2g/C^2)$

según la formulación de Bazin

	γ										
R	0,06	0,10	0,16	0,20	0,30	0,46	0,60	0,85	1,30	1,45	1,65	1,75
0,01	0,0066291	0,0103580	0,0175051	0,0233056	0,0414322	0,0812070	0,1268860	0,2337033	0,5075439	0,6221297	0,7930374	0,8862597
0,03	0,0046943	0,0064428	0,0095834	0,0120224	0,0193284	0,0346087	0,0516043	0,0903695	0,1873366	0,2274276	0,2869243	0,3192622
0,05	0,0041656	0,0054235	0,0076211	0,0092934	0,0141990	0,0242025	0,0351307	0,0596950	0,1202246	0,1450623	0,1818044	0,2017292
0,07	0,0038972	0,0049169	0,0066685	0,0079842	0,0117913	0,0194217	0,0276519	0,0459556	0,0905550	0,1087508	0,1356015	0,1501366
0,10	0,0036654	0,0044862	0,0058728	0,0069008	0,0098333	0,0156026	0,0217382	0,0352196	0,0676430	0,0807813	0,1001118	0,1105539
0,11	0,0036112	0,0043865	0,0056906	0,0066542	0,0093928	0,0147538	0,0204335	0,0328709	0,0626737	0,0747267	0,0924452	0,1020106
0,12	0,0035642	0,0043004	0,0055340	0,0064428	0,0090168	0,0140329	0,0193284	0,0308885	0,0584941	0,0696382	0,0860074	0,0948394
0,13	0,0035231	0,0042251	0,0053977	0,0062591	0,0086915	0,0134119	0,0183789	0,0291906	0,0549264	0,0652977	0,0805204	0,0887294
0,14	0,0034866	0,0041586	0,0052777	0,0060977	0,0084066	0,0128705	0,0175532	0,0277185	0,0518426	0,0615486	0,0757847	0,0834577
0,15	0,0034540	0,0040994	0,0051710	0,0059545	0,0081549	0,0123936	0,0168276	0,0264287	0,0491485	0,0582755	0,0716532	0,0788600
0,16	0,0034246	0,0040461	0,0050754	0,0058264	0,0079304	0,0119700	0,0161844	0,0252882	0,0467730	0,0553912	0,0680151	0,0748126
0,17	0,0033980	0,0039979	0,0049892	0,0057110	0,0077287	0,0115907	0,0156098	0,0242717	0,0446615	0,0528291	0,0647853	0,0712205
0,18	0,0033737	0,0039541	0,0049109	0,0056064	0,0075464	0,0112489	0,0150928	0,0233595	0,0427713	0,0505367	0,0618975	0,0680095
0,19	0,0033515	0,0039139	0,0048394	0,0055110	0,0073806	0,0109389	0,0146248	0,0225357	0,0410685	0,0484726	0,0592989	0,0651209
0,20	0,0033310	0,0038770	0,0047739	0,0054235	0,0072290	0,0106563	0,0141990	0,0217877	0,0395257	0,0466037	0,0569473	0,0625075
0,25	0,0032483	0,0037289	0,0045120	0,0050754	0,0066291	0,0095460	0,0125332	0,0188775	0,0335600	0,0393864	0,0478800	0,0524376
0,30	0,0031879	0,0036214	0,0043234	0,0048259	0,0062030	0,0087655	0,0113703	0,0168631	0,0294693	0,0344482	0,0416910	0,0455713
0,35	0,0031414	0,0035389	0,0041796	0,0046363	0,0058816	0,0081820	0,0105055	0,0153760	0,0264735	0,0308386	0,0371765	0,0405675
0,40	0,0031041	0,0034731	0,0040654	0,0044862	0,0056288	0,0077262	0,0098333	0,0142272	0,0241756	0,0280743	0,0337258	0,0367458
0,45	0,0030735	0,0034191	0,0039721	0,0043638	0,0054235	0,0073586	0,0092934	0,0133095	0,0223511	0,0258829	0,0309947	0,0337233
0,50	0,0030476	0,0033737	0,0038940	0,0042615	0,0052529	0,0070545	0,0088485	0,0125570	0,0208636	0,0240985	0,0287744	0,0312677
0,55	0,0030255	0,0033349	0,0038274	0,0041745	0,0051083	0,0067981	0,0084745	0,0119271	0,0196248	0,0226144	0,0269302	0,0292293
0,60	0,0030062	0,0033013	0,0037698	0,0040994	0,0049838	0,0065783	0,0081549	0,0113909	0,0185752	0,0213584	0,0253715	0,0275074
0,65	0,0029893	0,0032717	0,0037193	0,0040336	0,0048752	0,0063874	0,0078780	0,0109281	0,0176732	0,0202801	0,0240348	0,0260317
0,70	0,0029742	0,0032455	0,0036746	0,0039755	0,0047795	0,0062197	0,0076353	0,0105238	0,0168885	0,0193430	0,0228745	0,0247513
0,75	0,0029608	0,0032221	0,0036347	0,0039237	0,0046943	0,0060710	0,0074206	0,0101673	0,0161988	0,0185201	0,0218568	0,0236287
0,80	0,0029486	0,0032009	0,0035988	0,0038770	0,0046179	0,0059380	0,0072290	0,0098499	0,0155873	0,0177910	0,0209560	0,0226355
0,85	0,0029375	0,0031817	0,0035663	0,0038349	0,0045489	0,0058182	0,0070567	0,0095654	0,0150407	0,0171400	0,0201523	0,0217499
0,90	0,0029274	0,0031642	0,0035366	0,0037964	0,0044862	0,0057095	0,0069008	0,0093086	0,0145489	0,0165547	0,0194304	0,0209546
0,95	0,0029181	0,0031481	0,0035095	0,0037613	0,0044289	0,0056105	0,0067589	0,0090754	0,0141037	0,0160252	0,0187779	0,0202360
1,00	0,0029096	0,0031333	0,0034844	0,0037289	0,0043763	0,0055198	0,0066291	0,0088626	0,0136985	0,0155435	0,0181848	0,0195832
1,50	0,0028494	0,0030296	0,0033103	0,0035043	0,0040135	0,0049000	0,0057482	0,0074311	0,0110043	0,0123507	0,0142667	0,0152766
2,00	0,0028139	0,0029687	0,0032086	0,0033737	0,0038047	0,0045481	0,0052529	0,0066378	0,0095384	0,0106218	0,0121570	0,0129634
2,50	0,0027898	0,0029274	0,0031401	0,0032860	0,0036654	0,0043154	0,0049277	0,0061221	0,0085982	0,0095168	0,0108141	0,0114938
3,00	0,0027720	0,0028972	0,0030900	0,0032221	0,0035642	0,0041476	0,0046943	0,0057547	0,0079354	0,0087400	0,0098732	0,0104657
3,50	0,0027583	0,0028737	0,0030514	0,0031728	0,0034866	0,0040195	0,0045168	0,0054771	0,0074387	0,0081591	0,0091715	0,0096999
4,00	0,0027472	0,0028549	0,0030204	0,0031333	0,0034246	0,0039177	0,0043763	0,0052583	0,0070499	0,0077054	0,0086247	0,0091037
4,50	0,0027381	0,0028394	0,0029949	0,0031008	0,0033737	0,0038343	0,0042615	0,0050805	0,0067359	0,0073394	0,0081845	0,0086243
5,00	0,0027303	0,0028263	0,0029733	0,0030735	0,0033310	0,0037645	0,0041656	0,0049324	0,0064757	0,0070368	0,0078211	0,0082288
5,50	0,0027237	0,0028151	0,0029549	0,0030500	0,0032944	0,0037050	0,0040840	0,0048068	0,0062560	0,0067815	0,0075151	0,0078960
6,00	0,0027179	0,0028053	0,0029389	0,0030296	0,0032627	0,0036534	0,0040135	0,0046985	0,0060675	0,0065627	0,0072531	0,0076113

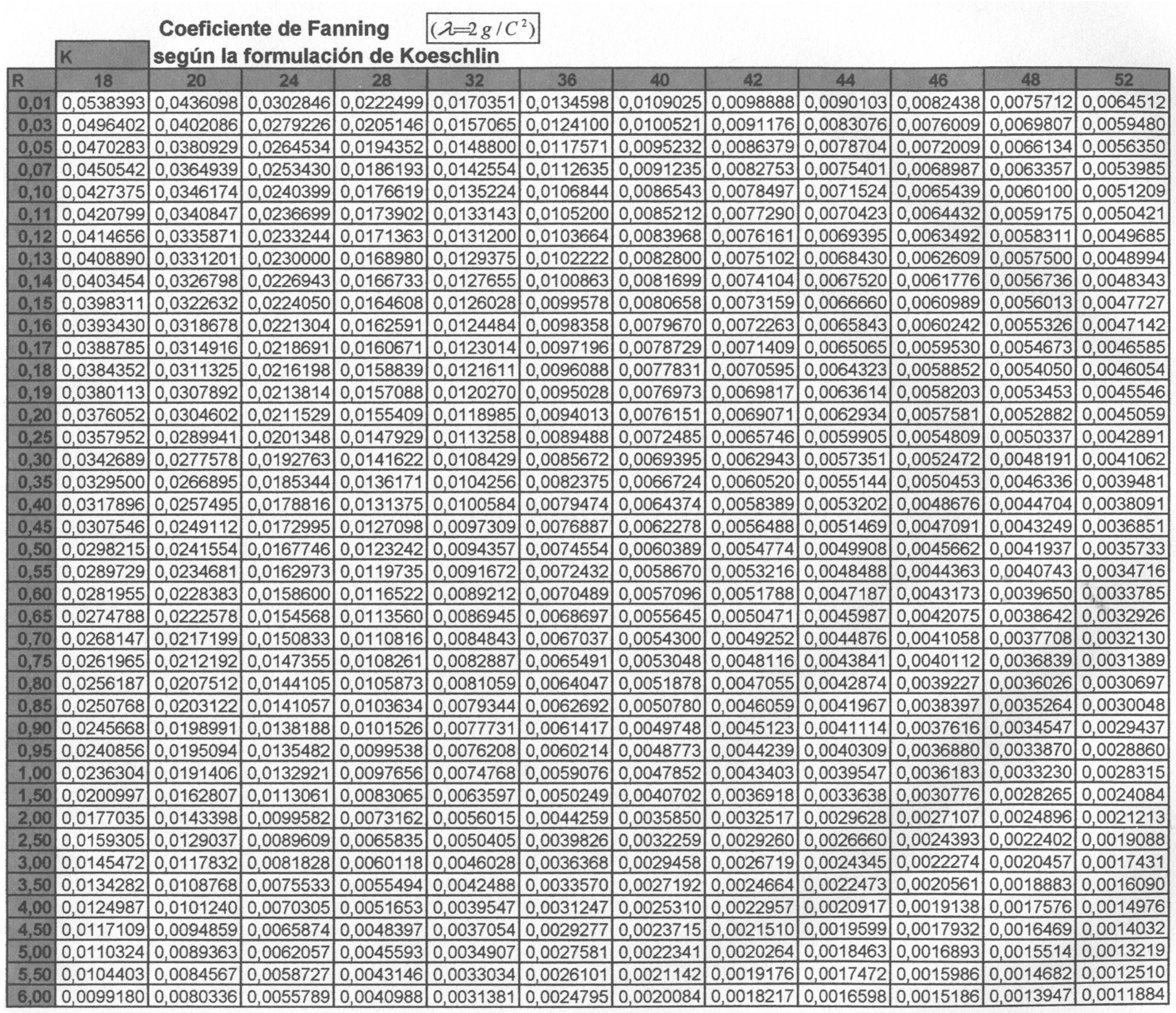
Table 6. Bazin formulation (simplified). Values of λ.

VALORES DE C= $K(1+0'6\times\sqrt{R})$

según la formulación de Koeschlin

	K										
R	**18**	**20**	**24**	**28**	**32**	**36**	**40**	**42**	**44**	**46**	**48**	**52**
0,01	19,08000	21,20000	25,44000	29,68000	33,92000	38,16000	42,40000	44,52000	46,64000	48,76000	50,88000	55,12000
0,03	19,87061	22,07846	26,49415	30,90985	35,32554	39,74123	44,15692	46,36477	48,57261	50,78046	52,98831	57,40400
0,05	20,41495	22,68328	27,21994	31,75659	36,29325	40,82991	45,36656	47,63489	49,90322	52,17155	54,43988	58,97653
0,07	20,85741	23,17490	27,80988	32,44486	37,07984	41,71482	46,34980	48,66729	50,98478	53,30227	55,61976	60,25474
0,10	21,41526	23,79473	28,55368	33,31263	38,07157	42,83052	47,58947	49,96894	52,34841	54,72789	57,10736	61,86631
0,11	21,58195	23,97995	28,77594	33,57193	38,36792	43,16391	47,95990	50,35789	52,75589	55,15388	57,55188	62,34787
0,12	21,74123	24,15692	28,98831	33,81969	38,65108	43,48246	48,31384	50,72954	53,14523	55,56092	57,97661	62,80800
0,13	21,89400	24,32666	29,19199	34,05733	38,92266	43,78799	48,65332	51,08599	53,51866	55,95132	58,38399	63,24932
0,14	22,04099	24,48999	29,38799	34,28598	39,18398	44,08198	48,97998	51,42898	53,87798	56,32697	58,77597	63,67397
0,15	22,18282	24,64758	29,57710	34,50661	39,43613	44,36564	49,29516	51,75992	54,22468	56,68943	59,15419	64,08371
0,16	22,32000	24,80000	29,76000	34,72000	39,68000	44,64000	49,60000	52,08000	54,56000	57,04000	59,52000	64,48000
0,17	22,45295	24,94773	29,93727	34,92682	39,91636	44,90591	49,89545	52,39023	54,88500	57,37977	59,87454	64,86409
0,18	22,58205	25,09117	30,10940	35,12764	40,14587	45,16410	50,18234	52,69145	55,20057	57,70969	60,21881	65,23704
0,19	22,70761	25,23068	30,27681	35,32295	40,36909	45,41522	50,46136	52,98443	55,50749	58,03056	60,55363	65,59976
0,20	22,82991	25,36656	30,43988	35,51319	40,58650	45,65981	50,73313	53,26978	55,80644	58,34310	60,87975	65,95306
0,25	23,40000	26,00000	31,20000	36,40000	41,60000	46,80000	52,00000	54,60000	57,20000	59,80000	62,40000	67,60000
0,30	23,91540	26,57267	31,88720	37,20174	42,51627	47,83081	53,14534	55,80261	58,45988	61,11714	63,77441	69,08894
0,35	24,38937	27,09930	32,51915	37,93901	43,35887	48,77873	54,19859	56,90852	59,61845	62,32838	65,03831	70,45817
0,40	24,83052	27,58947	33,10736	38,62525	44,14315	49,66104	55,17893	57,93788	60,69683	63,45577	66,21472	71,73261
0,45	25,24486	28,04984	33,65981	39,26978	44,87975	50,48972	56,09969	58,90467	61,70966	64,51464	67,31963	72,92960
0,50	25,63675	28,48528	34,18234	39,87939	45,57645	51,27351	56,97056	59,81909	62,66762	65,51615	68,36468	74,06173
0,55	26,00949	28,89944	34,67933	40,45921	46,23910	52,01899	57,79888	60,68882	63,57876	66,46871	69,35865	75,13854
0,60	26,36564	29,29516	35,15419	41,01322	46,87226	52,73129	58,59032	61,51984	64,44935	67,37887	70,30838	76,16742
0,65	26,70724	29,67471	35,60965	41,54459	47,47953	53,41448	59,34942	62,31689	65,28436	68,25183	71,21930	77,15424
0,70	27,03593	30,03992	36,04790	42,05589	48,06387	54,07186	60,07984	63,08383	66,08782	69,09182	72,09581	78,10379
0,75	27,35307	30,39230	36,47077	42,54923	48,62769	54,70615	60,78461	63,82384	66,86307	69,90230	72,94153	79,01999
0,80	27,65981	30,73313	36,87975	43,02638	49,17300	55,31963	61,46625	64,53957	67,61288	70,68619	73,75950	79,90613
0,85	27,95711	31,06345	37,27614	43,48883	49,70153	55,91422	62,12691	65,23325	68,33960	71,44594	74,55229	80,76498
0,90	28,24578	31,38420	37,66104	43,93788	50,21472	56,49156	62,76840	65,90682	69,04524	72,18366	75,32208	81,59892
0,95	28,52654	31,69615	38,03538	44,37461	50,71385	57,05308	63,39231	66,56192	69,73154	72,90115	76,07077	82,41000
1,00	28,80000	32,00000	38,40000	44,80000	51,20000	57,60000	64,00000	67,20000	70,40000	73,60000	76,80000	83,20000
1,50	31,22724	34,69694	41,63633	48,57571	55,51510	62,45449	69,39388	72,86357	76,33326	79,80296	83,27265	90,21204
2,00	33,27351	36,97056	44,36468	51,75879	59,15290	66,54701	73,94113	77,63818	81,33524	85,03229	88,72935	96,12346
2,50	35,07630	38,97367	46,76840	54,56313	62,35787	70,15260	77,94733	81,84470	85,74207	89,63943	93,53680	101,33153
3,00	36,70615	40,78461	48,94153	57,09845	65,25538	73,41230	81,56922	85,64768	89,72614	93,80460	97,88306	106,03999
3,50	38,20495	42,44994	50,93993	59,42992	67,91991	76,40990	84,89989	89,14488	93,38988	97,63487	101,87987	110,36986
4,00	39,60000	44,00000	52,80000	61,60000	70,40000	79,20000	88,00000	92,40000	96,80000	101,20000	105,60000	114,40000
4,50	40,91026	45,45584	54,54701	63,63818	72,72935	81,82052	90,91169	95,45727	100,00286	104,54844	109,09403	118,18519
5,00	42,14953	46,83282	56,19938	65,56594	74,93251	84,29907	93,66563	98,34891	103,03219	107,71548	112,39876	121,76532
5,50	43,32825	48,14249	57,77099	67,39949	77,02799	86,65649	96,28499	101,09924	105,91349	110,72774	115,54199	125,17049
6,00	44,45449	49,39388	59,27265	69,15143	79,03020	88,90898	98,78775	103,72714	108,66653	113,60592	118,54530	128,42408

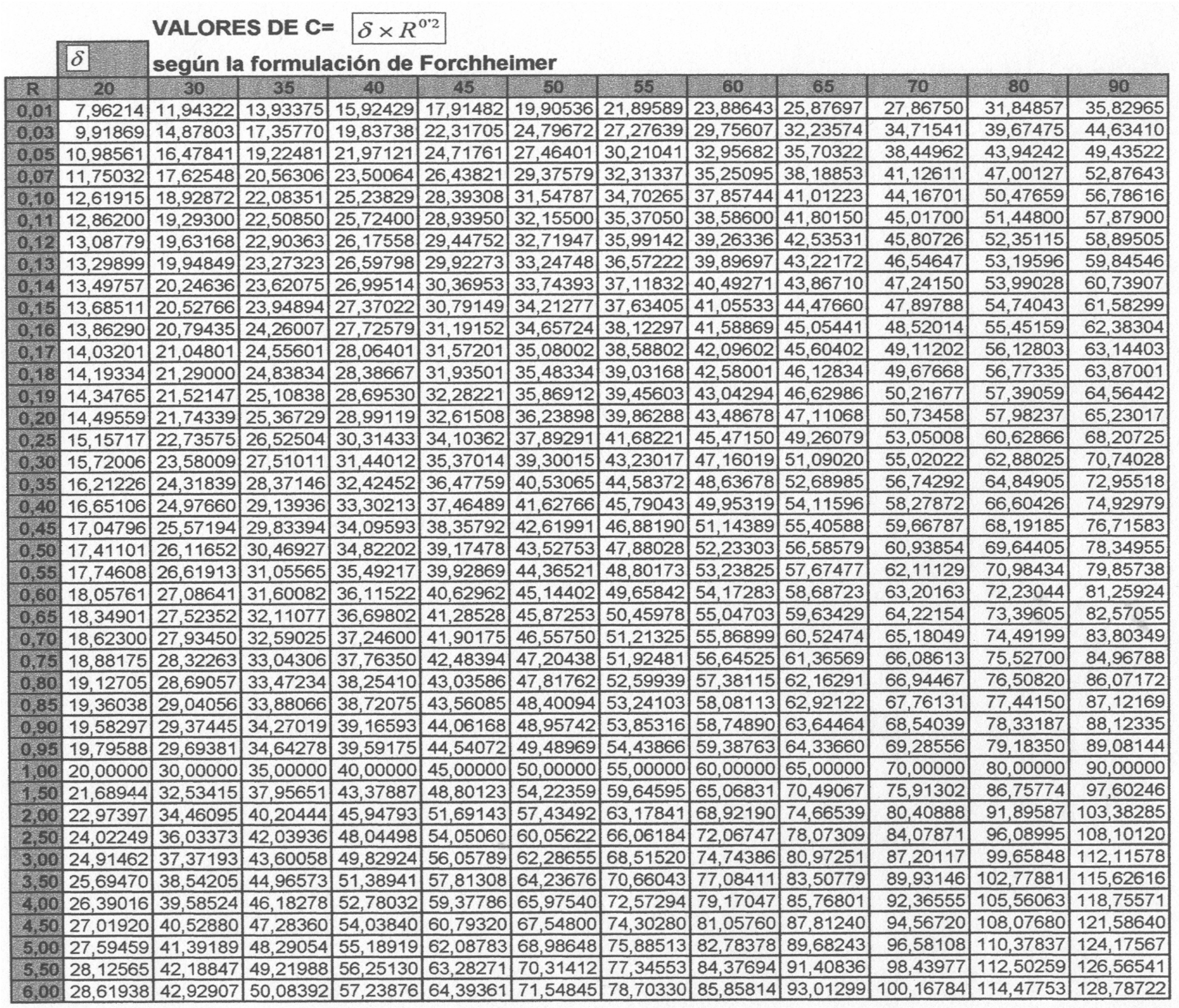
Table 7. Koeschlin formulation (simplified). Values of C.



Coeficiente de Fanning $(\lambda = 2g/C^2)$
según la formulación de Koeschlin

	K											
R	18	20	24	28	32	36	40	42	44	46	48	52
0,01	0,0538393	0,0436098	0,0302846	0,0222499	0,0170351	0,0134598	0,0109025	0,0098888	0,0090103	0,0082438	0,0075712	0,0064512
0,03	0,0496402	0,0402086	0,0279226	0,0205146	0,0157065	0,0124100	0,0100521	0,0091176	0,0083076	0,0076009	0,0069807	0,0059480
0,05	0,0470283	0,0380929	0,0264534	0,0194352	0,0148800	0,0117571	0,0095232	0,0086379	0,0078704	0,0072009	0,0066134	0,0056350
0,07	0,0450542	0,0364939	0,0253430	0,0186193	0,0142554	0,0112635	0,0091235	0,0082753	0,0075401	0,0068987	0,0063357	0,0053985
0,10	0,0427375	0,0346174	0,0240399	0,0176619	0,0135224	0,0106844	0,0086543	0,0078497	0,0071524	0,0065439	0,0060100	0,0051209
0,11	0,0420799	0,0340847	0,0236699	0,0173902	0,0133143	0,0105200	0,0085212	0,0077290	0,0070423	0,0064432	0,0059175	0,0050421
0,12	0,0414656	0,0335871	0,0233244	0,0171363	0,0131200	0,0103664	0,0083968	0,0076161	0,0069395	0,0063492	0,0058311	0,0049685
0,13	0,0408890	0,0331201	0,0230000	0,0168980	0,0129375	0,0102222	0,0082800	0,0075102	0,0068430	0,0062609	0,0057500	0,0048994
0,14	0,0403454	0,0326798	0,0226943	0,0166733	0,0127655	0,0100863	0,0081699	0,0074104	0,0067520	0,0061776	0,0056736	0,0048343
0,15	0,0398311	0,0322632	0,0224050	0,0164608	0,0126028	0,0099578	0,0080658	0,0073159	0,0066660	0,0060989	0,0056013	0,0047727
0,16	0,0393430	0,0318678	0,0221304	0,0162591	0,0124484	0,0098358	0,0079670	0,0072263	0,0065843	0,0060242	0,0055326	0,0047142
0,17	0,0388785	0,0314916	0,0218691	0,0160671	0,0123014	0,0097196	0,0078729	0,0071409	0,0065065	0,0059530	0,0054673	0,0046585
0,18	0,0384352	0,0311325	0,0216198	0,0158839	0,0121611	0,0096088	0,0077831	0,0070595	0,0064323	0,0058852	0,0054050	0,0046054
0,19	0,0380113	0,0307892	0,0213814	0,0157088	0,0120270	0,0095028	0,0076973	0,0069817	0,0063614	0,0058203	0,0053453	0,0045546
0,20	0,0376052	0,0304602	0,0211529	0,0155409	0,0118985	0,0094013	0,0076151	0,0069071	0,0062934	0,0057581	0,0052882	0,0045059
0,25	0,0357952	0,0289941	0,0201348	0,0147929	0,0113258	0,0089488	0,0072485	0,0065746	0,0059905	0,0054809	0,0050337	0,0042891
0,30	0,0342689	0,0277578	0,0192763	0,0141622	0,0108429	0,0085672	0,0069395	0,0062943	0,0057351	0,0052472	0,0048191	0,0041062
0,35	0,0329500	0,0266895	0,0185344	0,0136171	0,0104256	0,0082375	0,0066724	0,0060520	0,0055144	0,0050453	0,0046336	0,0039481
0,40	0,0317896	0,0257495	0,0178816	0,0131375	0,0100584	0,0079474	0,0064374	0,0058389	0,0053202	0,0048676	0,0044704	0,0038091
0,45	0,0307546	0,0249112	0,0172995	0,0127098	0,0097309	0,0076887	0,0062278	0,0056488	0,0051469	0,0047091	0,0043249	0,0036851
0,50	0,0298215	0,0241554	0,0167746	0,0123242	0,0094357	0,0074554	0,0060389	0,0054774	0,0049908	0,0045662	0,0041937	0,0035733
0,55	0,0289729	0,0234681	0,0162973	0,0119735	0,0091672	0,0072432	0,0058670	0,0053216	0,0048488	0,0044363	0,0040743	0,0034716
0,60	0,0281955	0,0228383	0,0158600	0,0116522	0,0089212	0,0070489	0,0057096	0,0051788	0,0047187	0,0043173	0,0039650	0,0033785
0,65	0,0274788	0,0222578	0,0154568	0,0113560	0,0086945	0,0068697	0,0055645	0,0050471	0,0045987	0,0042075	0,0038642	0,0032926
0,70	0,0268147	0,0217199	0,0150833	0,0110816	0,0084843	0,0067037	0,0054300	0,0049252	0,0044876	0,0041058	0,0037708	0,0032130
0,75	0,0261965	0,0212192	0,0147355	0,0108261	0,0082887	0,0065491	0,0053048	0,0048116	0,0043841	0,0040112	0,0036839	0,0031389
0,80	0,0256187	0,0207512	0,0144105	0,0105873	0,0081059	0,0064047	0,0051878	0,0047055	0,0042874	0,0039227	0,0036026	0,0030697
0,85	0,0250768	0,0203122	0,0141057	0,0103634	0,0079344	0,0062692	0,0050780	0,0046059	0,0041967	0,0038397	0,0035264	0,0030048
0,90	0,0245668	0,0198991	0,0138188	0,0101526	0,0077731	0,0061417	0,0049748	0,0045123	0,0041114	0,0037616	0,0034547	0,0029437
0,95	0,0240856	0,0195094	0,0135482	0,0099538	0,0076208	0,0060214	0,0048773	0,0044239	0,0040309	0,0036880	0,0033870	0,0028860
1,00	0,0236304	0,0191406	0,0132921	0,0097656	0,0074768	0,0059076	0,0047852	0,0043403	0,0039547	0,0036183	0,0033230	0,0028315
1,50	0,0200997	0,0162807	0,0113061	0,0083065	0,0063597	0,0050249	0,0040702	0,0036918	0,0033638	0,0030776	0,0028265	0,0024084
2,00	0,0177035	0,0143398	0,0099582	0,0073162	0,0056015	0,0044259	0,0035850	0,0032517	0,0029628	0,0027107	0,0024896	0,0021213
2,50	0,0159305	0,0129037	0,0089609	0,0065835	0,0050405	0,0039826	0,0032259	0,0029260	0,0026660	0,0024393	0,0022402	0,0019088
3,00	0,0145472	0,0117832	0,0081828	0,0060118	0,0046028	0,0036368	0,0029458	0,0026719	0,0024345	0,0022274	0,0020457	0,0017431
3,50	0,0134282	0,0108768	0,0075533	0,0055494	0,0042488	0,0033570	0,0027192	0,0024664	0,0022473	0,0020561	0,0018883	0,0016090
4,00	0,0124987	0,0101240	0,0070305	0,0051653	0,0039547	0,0031247	0,0025310	0,0022957	0,0020917	0,0019138	0,0017576	0,0014976
4,50	0,0117109	0,0094859	0,0065874	0,0048397	0,0037054	0,0029277	0,0023715	0,0021510	0,0019599	0,0017932	0,0016469	0,0014032
5,00	0,0110324	0,0089363	0,0062057	0,0045593	0,0034907	0,0027581	0,0022341	0,0020264	0,0018463	0,0016893	0,0015514	0,0013219
5,50	0,0104403	0,0084567	0,0058727	0,0043146	0,0033034	0,0026101	0,0021142	0,0019176	0,0017472	0,0015986	0,0014682	0,0012510
6,00	0,0099180	0,0080336	0,0055789	0,0040988	0,0031381	0,0024795	0,0020084	0,0018217	0,0016598	0,0015186	0,0013947	0,0011884

Table 8. Koeschlin formulation (simplified). Values of λ.



VALORES DE C= $\delta \times R^{0'2}$

δ según la formulación de Forchheimer

R	20	30	35	40	45	50	55	60	65	70	80	90
0,01	7,96214	11,94322	13,93375	15,92429	17,91482	19,90536	21,89589	23,88643	25,87697	27,86750	31,84857	35,82965
0,03	9,91869	14,87803	17,35770	19,83738	22,31705	24,79672	27,27639	29,75607	32,23574	34,71541	39,67475	44,63410
0,05	10,98561	16,47841	19,22481	21,97121	24,71761	27,46401	30,21041	32,95682	35,70322	38,44962	43,94242	49,43522
0,07	11,75032	17,62548	20,56306	23,50064	26,43821	29,37579	32,31337	35,25095	38,18853	41,12611	47,00127	52,87643
0,10	12,61915	18,92872	22,08351	25,23829	28,39308	31,54787	34,70265	37,85744	41,01223	44,16701	50,47659	56,78616
0,11	12,86200	19,29300	22,50850	25,72400	28,93950	32,15500	35,37050	38,58600	41,80150	45,01700	51,44800	57,87900
0,12	13,08779	19,63168	22,90363	26,17558	29,44752	32,71947	35,99142	39,26336	42,53531	45,80726	52,35115	58,89505
0,13	13,29899	19,94849	23,27323	26,59798	29,92273	33,24748	36,57222	39,89697	43,22172	46,54647	53,19596	59,84546
0,14	13,49757	20,24636	23,62075	26,99514	30,36953	33,74393	37,11832	40,49271	43,86710	47,24150	53,99028	60,73907
0,15	13,68511	20,52766	23,94894	27,37022	30,79149	34,21277	37,63405	41,05533	44,47660	47,89788	54,74043	61,58299
0,16	13,86290	20,79435	24,26007	27,72579	31,19152	34,65724	38,12297	41,58869	45,05441	48,52014	55,45159	62,38304
0,17	14,03201	21,04801	24,55601	28,06401	31,57201	35,08002	38,58802	42,09602	45,60402	49,11202	56,12803	63,14403
0,18	14,19334	21,29000	24,83834	28,38667	31,93501	35,48334	39,03168	42,58001	46,12834	49,67668	56,77335	63,87001
0,19	14,34765	21,52147	25,10838	28,69530	32,28221	35,86912	39,45603	43,04294	46,62986	50,21677	57,39059	64,56442
0,20	14,49559	21,74339	25,36729	28,99119	32,61508	36,23898	39,86288	43,48678	47,11068	50,73458	57,98237	65,23017
0,25	15,15717	22,73575	26,52504	30,31433	34,10362	37,89291	41,68221	45,47150	49,26079	53,05008	60,62866	68,20725
0,30	15,72006	23,58009	27,51011	31,44012	35,37014	39,30015	43,23017	47,16019	51,09020	55,02022	62,88025	70,74028
0,35	16,21226	24,31839	28,37146	32,42452	36,47759	40,53065	44,58372	48,63678	52,68985	56,74292	64,84905	72,95518
0,40	16,65106	24,97660	29,13936	33,30213	37,46489	41,62766	45,79043	49,95319	54,11596	58,27872	66,60426	74,92979
0,45	17,04796	25,57194	29,83394	34,09593	38,35792	42,61991	46,88190	51,14389	55,40588	59,66787	68,19185	76,71583
0,50	17,41101	26,11652	30,46927	34,82202	39,17478	43,52753	47,88028	52,23303	56,58579	60,93854	69,64405	78,34955
0,55	17,74608	26,61913	31,05565	35,49217	39,92869	44,36521	48,80173	53,23825	57,67477	62,11129	70,98434	79,85738
0,60	18,05761	27,08641	31,60082	36,11522	40,62962	45,14402	49,65842	54,17283	58,68723	63,20163	72,23044	81,25924
0,65	18,34901	27,52352	32,11077	36,69802	41,28528	45,87253	50,45978	55,04703	59,63429	64,22154	73,39605	82,57055
0,70	18,62300	27,93450	32,59025	37,24600	41,90175	46,55750	51,21325	55,86899	60,52474	65,18049	74,49199	83,80349
0,75	18,88175	28,32263	33,04306	37,76350	42,48394	47,20438	51,92481	56,64525	61,36569	66,08613	75,52700	84,96788
0,80	19,12705	28,69057	33,47234	38,25410	43,03586	47,81762	52,59939	57,38115	62,16291	66,94467	76,50820	86,07172
0,85	19,36038	29,04056	33,88066	38,72075	43,56085	48,40094	53,24103	58,08113	62,92122	67,76131	77,44150	87,12169
0,90	19,58297	29,37445	34,27019	39,16593	44,06168	48,95742	53,85316	58,74890	63,64464	68,54039	78,33187	88,12335
0,95	19,79588	29,69381	34,64278	39,59175	44,54072	49,48969	54,43866	59,38763	64,33660	69,28556	79,18350	89,08144
1,00	20,00000	30,00000	35,00000	40,00000	45,00000	50,00000	55,00000	60,00000	65,00000	70,00000	80,00000	90,00000
1,50	21,68944	32,53415	37,95651	43,37887	48,80123	54,22359	59,64595	65,06831	70,49067	75,91302	86,75774	97,60246
2,00	22,97397	34,46095	40,20444	45,94793	51,69143	57,43492	63,17841	68,92190	74,66539	80,40888	91,89587	103,38285
2,50	24,02249	36,03373	42,03936	48,04498	54,05060	60,05622	66,06184	72,06747	78,07309	84,07871	96,08995	108,10120
3,00	24,91462	37,37193	43,60058	49,82924	56,05789	62,28655	68,51520	74,74386	80,97251	87,20117	99,65848	112,11578
3,50	25,69470	38,54205	44,96573	51,38941	57,81308	64,23676	70,66043	77,08411	83,50779	89,93146	102,77881	115,62616
4,00	26,39016	39,58524	46,18278	52,78032	59,37786	65,97540	72,57294	79,17047	85,76801	92,36555	105,56063	118,75571
4,50	27,01920	40,52880	47,28360	54,03840	60,79320	67,54800	74,30280	81,05760	87,81240	94,56720	108,07680	121,58640
5,00	27,59459	41,39189	48,29054	55,18919	62,08783	68,98648	75,88513	82,78378	89,68243	96,58108	110,37837	124,17567
5,50	28,12565	42,18847	49,21988	56,25130	63,28271	70,31412	77,34553	84,37694	91,40836	98,43977	112,50259	126,56541
6,00	28,61938	42,92907	50,08392	57,23876	64,39361	71,54845	78,70330	85,85814	93,01299	100,16784	114,47753	128,78722

Table 9. Forchheimer formulation (simplified). Values of C.

Coeficiente de Fanning $(\lambda = 2g/C^2)$

según la formulación de Forchheimer

	δ											
R	**20**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**80**	**90**
0,01	0,3091691	0,1374085	0,1009532	0,0772923	0,0610704	0,0494671	0,0408819	0,0343521	0,0292704	0,0252383	0,0193231	0,0152676
0,03	0,1992267	0,0885452	0,0650536	0,0498067	0,0393534	0,0318763	0,0263440	0,0221363	0,0188617	0,0162634	0,0124517	0,0098384
0,05	0,1624082	0,0721814	0,0530313	0,0406021	0,0320806	0,0259853	0,0214755	0,0180454	0,0153759	0,0132578	0,0101505	0,0080202
0,07	0,1419570	0,0630920	0,0463533	0,0354893	0,0280409	0,0227131	0,0187712	0,0157730	0,0134397	0,0115883	0,0088723	0,0070102
0,10	0,1230824	0,0547033	0,0401902	0,0307706	0,0243126	0,0196932	0,0162754	0,0136758	0,0116528	0,0100475	0,0076927	0,0060781
0,11	0,1184784	0,0526570	0,0386868	0,0296196	0,0234031	0,0189565	0,0156666	0,0131643	0,0112169	0,0096717	0,0074049	0,0058508
0,12	0,1144257	0,0508559	0,0373635	0,0286064	0,0226026	0,0183081	0,0151307	0,0127140	0,0108332	0,0093409	0,0071516	0,0056507
0,13	0,1108202	0,0492534	0,0361862	0,0277050	0,0218904	0,0177312	0,0146539	0,0123134	0,0104918	0,0090465	0,0069263	0,0054726
0,14	0,1075833	0,0478148	0,0351292	0,0268958	0,0212510	0,0172133	0,0142259	0,0119537	0,0101854	0,0087823	0,0067240	0,0053128
0,15	0,1046549	0,0465133	0,0341730	0,0261637	0,0206726	0,0167448	0,0138387	0,0116283	0,0099082	0,0085433	0,0065409	0,0051681
0,16	0,1019878	0,0453279	0,0333021	0,0254969	0,0201457	0,0163180	0,0134860	0,0113320	0,0096556	0,0083255	0,0063742	0,0050364
0,17	0,0995443	0,0442419	0,0325043	0,0248861	0,0196631	0,0159271	0,0131629	0,0110605	0,0094243	0,0081261	0,0062215	0,0049158
0,18	0,0972942	0,0432419	0,0317695	0,0243236	0,0192186	0,0155671	0,0128654	0,0108105	0,0092113	0,0079424	0,0060809	0,0048047
0,19	0,0952126	0,0423167	0,0310898	0,0238032	0,0188074	0,0152340	0,0125901	0,0105792	0,0090142	0,0077725	0,0059508	0,0047019
0,20	0,0932790	0,0414574	0,0304585	0,0233198	0,0184255	0,0149246	0,0123344	0,0103643	0,0088312	0,0076146	0,0058299	0,0046064
0,25	0,0853140	0,0379173	0,0278576	0,0213285	0,0168521	0,0136502	0,0112812	0,0094793	0,0080771	0,0069644	0,0053321	0,0042130
0,30	0,0793136	0,0352505	0,0258983	0,0198284	0,0156669	0,0126902	0,0104877	0,0088126	0,0075090	0,0064746	0,0049571	0,0039167
0,35	0,0745708	0,0331426	0,0243497	0,0186427	0,0147300	0,0119313	0,0098606	0,0082856	0,0070600	0,0060874	0,0046607	0,0036825
0,40	0,0706923	0,0314188	0,0230832	0,0176731	0,0139639	0,0113108	0,0093477	0,0078547	0,0066928	0,0057708	0,0044183	0,0034910
0,45	0,0674390	0,0299729	0,0220209	0,0168597	0,0133213	0,0107902	0,0089176	0,0074932	0,0063848	0,0055052	0,0042149	0,0033303
0,50	0,0646559	0,0287360	0,0211121	0,0161640	0,0127715	0,0103449	0,0085495	0,0071840	0,0061213	0,0052780	0,0040410	0,0031929
0,55	0,0622373	0,0276610	0,0203224	0,0155593	0,0122938	0,0099580	0,0082297	0,0069153	0,0058923	0,0050806	0,0038898	0,0030734
0,60	0,0601085	0,0267149	0,0196273	0,0150271	0,0118733	0,0096174	0,0079482	0,0066787	0,0056907	0,0049068	0,0037568	0,0029683
0,65	0,0582144	0,0258731	0,0190088	0,0145536	0,0114991	0,0093143	0,0076978	0,0064683	0,0055114	0,0047522	0,0036384	0,0028748
0,70	0,0565141	0,0251174	0,0184536	0,0141285	0,0111633	0,0090423	0,0074729	0,0062793	0,0053504	0,0046134	0,0035321	0,0027908
0,75	0,0549758	0,0244337	0,0179513	0,0137440	0,0108594	0,0087961	0,0072695	0,0061084	0,0052048	0,0044878	0,0034360	0,0027149
0,80	0,0535747	0,0238110	0,0174938	0,0133937	0,0105827	0,0085720	0,0070843	0,0059527	0,0050722	0,0043734	0,0033484	0,0026457
0,85	0,0522912	0,0232405	0,0170747	0,0130728	0,0103291	0,0083666	0,0069145	0,0058101	0,0049506	0,0042687	0,0032682	0,0025823
0,90	0,0511092	0,0227152	0,0166887	0,0127773	0,0100956	0,0081775	0,0067582	0,0056788	0,0048387	0,0041722	0,0031943	0,0025239
0,95	0,0500157	0,0222292	0,0163317	0,0125039	0,0098797	0,0080025	0,0066137	0,0055573	0,0047352	0,0040829	0,0031260	0,0024699
1,00	0,0490000	0,0217778	0,0160000	0,0122500	0,0096790	0,0078400	0,0064793	0,0054444	0,0046391	0,0040000	0,0030625	0,0024198
1,50	0,0416639	0,0185173	0,0136045	0,0104160	0,0082299	0,0066662	0,0055093	0,0046293	0,0039445	0,0034011	0,0026040	0,0020575
2,00	0,0371351	0,0165045	0,0121257	0,0092838	0,0073353	0,0059416	0,0049104	0,0041261	0,0035157	0,0030314	0,0023209	0,0018338
2,50	0,0339641	0,0150952	0,0110903	0,0084910	0,0067090	0,0054343	0,0044911	0,0037738	0,0032155	0,0027726	0,0021228	0,0016772
3,00	0,0315753	0,0140335	0,0103103	0,0078938	0,0062371	0,0050520	0,0041752	0,0035084	0,0029894	0,0025776	0,0019735	0,0015593
3,50	0,0296872	0,0131943	0,0096938	0,0074218	0,0058641	0,0047499	0,0039256	0,0032986	0,0028106	0,0024234	0,0018554	0,0014660
4,00	0,0281431	0,0125080	0,0091896	0,0070358	0,0055591	0,0045029	0,0037214	0,0031270	0,0026644	0,0022974	0,0017589	0,0013898
4,50	0,0268479	0,0119324	0,0087667	0,0067120	0,0053033	0,0042957	0,0035501	0,0029831	0,0025418	0,0021917	0,0016780	0,0013258
5,00	0,0257400	0,0114400	0,0084049	0,0064350	0,0050844	0,0041184	0,0034036	0,0028600	0,0024369	0,0021012	0,0016087	0,0012711
5,50	0,0247771	0,0110121	0,0080905	0,0061943	0,0048942	0,0039643	0,0032763	0,0027530	0,0023458	0,0020226	0,0015486	0,0012236
6,00	0,0239296	0,0106354	0,0078137	0,0059824	0,0047268	0,0038287	0,0031642	0,0026588	0,0022655	0,0019534	0,0014956	0,0011817

Table 10. Forchheimer formulation (simplified). Values of λ.

Coeficiente promedio de Fanning (λ)

	Categorías de rugosidad											
R	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0,01	0,009385	0,012974	0,018981	0,024671	0,035748	0,055700	0,075306	0,119778	0,214309	0,300843	0,436043	0,631222
0,03	0,006480	0,008671	0,012154	0,015334	0,021306	0,030956	0,040904	0,060398	0,101041	0,140594	0,199473	0,287703
0,05	0,005553	0,007329	0,010097	0,012596	0,017227	0,024385	0,031939	0,045781	0,074381	0,103110	0,144898	0,208463
0,07	0,005040	0,006594	0,008988	0,011137	0,015090	0,021042	0,027420	0,038628	0,061659	0,085281	0,119144	0,171082
0,10	0,004563	0,005917	0,007977	0,009820	0,013186	0,018128	0,023507	0,032576	0,051113	0,070542	0,097992	0,140399
0,11	0,004446	0,005751	0,007732	0,009502	0,012729	0,017440	0,022586	0,031173	0,048703	0,067180	0,093188	0,133433
0,12	0,004342	0,005604	0,007516	0,009222	0,012330	0,016840	0,021786	0,029961	0,046632	0,064292	0,089069	0,127462
0,13	0,004249	0,005474	0,007324	0,008974	0,011976	0,016312	0,021081	0,028900	0,044828	0,061777	0,085488	0,122273
0,14	0,004165	0,005356	0,007152	0,008752	0,011660	0,015841	0,020455	0,027961	0,043238	0,059563	0,082340	0,117711
0,15	0,004089	0,005249	0,006996	0,008551	0,011374	0,015419	0,019893	0,027122	0,041824	0,057594	0,079544	0,113661
0,16	0,004019	0,005152	0,006853	0,008368	0,011115	0,015036	0,019385	0,026367	0,040555	0,055829	0,077040	0,110034
0,17	0,003955	0,005062	0,006723	0,008200	0,010878	0,014687	0,018922	0,025682	0,039409	0,054234	0,074780	0,106763
0,18	0,003896	0,004979	0,006602	0,008046	0,010660	0,014368	0,018498	0,025057	0,038366	0,052784	0,072729	0,103794
0,19	0,003841	0,004902	0,006491	0,007903	0,010459	0,014074	0,018109	0,024483	0,037413	0,051459	0,070855	0,101082
0,20	0,003789	0,004831	0,006387	0,007771	0,010273	0,013802	0,017748	0,023954	0,036537	0,050241	0,069135	0,098594
0,25	0,003575	0,004533	0,005958	0,007223	0,009505	0,012690	0,016279	0,021815	0,033018	0,045356	0,062251	0,088639
0,30	0,003410	0,004305	0,005632	0,006808	0,008928	0,011861	0,015187	0,020243	0,030459	0,041807	0,057266	0,081438
0,35	0,003278	0,004123	0,005372	0,006479	0,008471	0,011211	0,014332	0,019021	0,028488	0,039076	0,053440	0,075917
0,40	0,003168	0,003971	0,005157	0,006208	0,008097	0,010681	0,013636	0,018034	0,026908	0,036888	0,050382	0,071507
0,45	0,003074	0,003843	0,004976	0,005980	0,007782	0,010238	0,013055	0,017215	0,025603	0,035082	0,047862	0,067877
0,50	0,002993	0,003732	0,004820	0,005783	0,007513	0,009859	0,012560	0,016519	0,024501	0,033558	0,045738	0,064819
0,55	0,002922	0,003635	0,004683	0,005612	0,007278	0,009531	0,012130	0,015918	0,023554	0,032247	0,043915	0,062195
0,60	0,002858	0,003549	0,004562	0,005460	0,007070	0,009242	0,011752	0,015391	0,022727	0,031104	0,042326	0,059911
0,65	0,002801	0,003471	0,004454	0,005324	0,006885	0,008985	0,011416	0,014925	0,021997	0,030095	0,040925	0,057898
0,70	0,002750	0,003401	0,004356	0,005202	0,006718	0,008754	0,011115	0,014508	0,021345	0,029196	0,039677	0,056105
0,75	0,002703	0,003337	0,004268	0,005091	0,006567	0,008545	0,010842	0,014131	0,020760	0,028386	0,038555	0,054494
0,80	0,002659	0,003279	0,004186	0,004989	0,006429	0,008355	0,010594	0,013789	0,020229	0,027653	0,037539	0,053036
0,85	0,002619	0,003225	0,004111	0,004896	0,006302	0,008180	0,010367	0,013476	0,019744	0,026984	0,036613	0,051708
0,90	0,002582	0,003175	0,004042	0,004810	0,006185	0,008019	0,010157	0,013188	0,019300	0,026370	0,035764	0,050491
0,95	0,002548	0,003128	0,003978	0,004730	0,006077	0,007870	0,009963	0,012923	0,018890	0,025805	0,034981	0,049370
1,00	0,002516	0,003085	0,003918	0,004655	0,005976	0,007732	0,009783	0,012676	0,018511	0,025281	0,034258	0,048333
1,50	0,002278	0,002765	0,003478	0,004108	0,005239	0,006729	0,008479	0,010903	0,015800	0,021540	0,029096	0,040951

Table 11.1. Average coefficient of Fanning.

Coeficiente promedio de Fanning (λ)

	Categorías de rugosidad											
R	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2,00	0,002126	0,002561	0,003200	0,003764	0,004778	0,006105	0,007669	0,009811	0,014149	0,019262	0,025961	0,036478
2,50	0,002018	0,002416	0,003003	0,003520	0,004451	0,005666	0,007100	0,009048	0,013001	0,017678	0,023784	0,033377
3,00	0,001935	0,002306	0,002852	0,003335	0,004203	0,005334	0,006669	0,008473	0,012139	0,016490	0,022153	0,031055
3,50	0,001869	0,002217	0,002733	0,003188	0,004007	0,005071	0,006328	0,008019	0,011461	0,015554	0,020869	0,029229
4,00	0,001814	0,002145	0,002634	0,003066	0,003845	0,004855	0,006049	0,007647	0,010907	0,014790	0,019822	0,027741
4,50	0,001769	0,002084	0,002552	0,002964	0,003709	0,004673	0,005814	0,007336	0,010443	0,014150	0,018945	0,026496
5,00	0,001729	0,002031	0,002481	0,002877	0,003593	0,004518	0,005613	0,007069	0,010047	0,013603	0,018197	0,025433
5,50	0,001695	0,001985	0,002419	0,002801	0,003491	0,004383	0,005438	0,006838	0,009704	0,013129	0,017547	0,024512
6,00	0,001665	0,001945	0,002364	0,002734	0,003402	0,004264	0,005284	0,006634	0,009402	0,012712	0,016977	0,023702
6,50	0,001638	0,001909	0,002316	0,002674	0,003322	0,004158	0,005147	0,006453	0,009133	0,012342	0,016469	0,022983
7,00	0,001614	0,001877	0,002272	0,002620	0,003251	0,004063	0,005023	0,006290	0,008892	0,012009	0,016015	0,022338
7,50	0,001592	0,001848	0,002233	0,002572	0,003186	0,003977	0,004912	0,006143	0,008675	0,011709	0,015604	0,021755
8,00	0,001572	0,001822	0,002197	0,002528	0,003127	0,003899	0,004810	0,006009	0,008477	0,011435	0,015230	0,021225
8,50	0,001554	0,001797	0,002164	0,002487	0,003073	0,003827	0,004717	0,005887	0,008295	0,011185	0,014888	0,020739
9,00	0,001537	0,001775	0,002134	0,002450	0,003023	0,003761	0,004632	0,005774	0,008129	0,010954	0,014573	0,020293
9,50	0,001522	0,001754	0,002106	0,002415	0,002977	0,003699	0,004552	0,005669	0,007975	0,010742	0,014282	0,019881
10,00	0,001507	0,001735	0,002080	0,002383	0,002935	0,003643	0,004479	0,005573	0,007831	0,010544	0,014012	0,019498
10,50	0,001494	0,001718	0,002056	0,002353	0,002895	0,003590	0,004410	0,005482	0,007698	0,010360	0,013760	0,019141
11,00	0,001482	0,001701	0,002033	0,002325	0,002858	0,003540	0,004346	0,005398	0,007574	0,010187	0,013525	0,018807
11,50	0,001470	0,001685	0,002012	0,002299	0,002823	0,003494	0,004286	0,005319	0,007457	0,010026	0,013304	0,018495
12,00	0,001459	0,001671	0,001992	0,002275	0,002790	0,003450	0,004229	0,005244	0,007347	0,009874	0,013097	0,018201
12,50	0,001449	0,001657	0,001973	0,002251	0,002759	0,003409	0,004176	0,005174	0,007243	0,009731	0,012901	0,017924
13,00	0,001439	0,001644	0,001955	0,002230	0,002729	0,003370	0,004125	0,005108	0,007145	0,009596	0,012717	0,017662
13,50	0,001430	0,001631	0,001939	0,002209	0,002702	0,003333	0,004077	0,005045	0,007053	0,009467	0,012542	0,017414
14,00	0,001421	0,001620	0,001923	0,002189	0,002675	0,003298	0,004032	0,004985	0,006965	0,009346	0,012376	0,017179
14,50	0,001413	0,001609	0,001908	0,002170	0,002650	0,003264	0,003989	0,004929	0,006881	0,009230	0,012218	0,016955
15,00	0,001405	0,001598	0,001893	0,002153	0,002626	0,003233	0,003948	0,004875	0,006802	0,009120	0,012068	0,016742
15,50	0,001397	0,001588	0,001879	0,002136	0,002604	0,003202	0,003908	0,004823	0,006726	0,009015	0,011924	0,016539

Table 11.2. Average coefficient of Fanning.

Channel class	Categ. (K)	Roughness	Channel typology
Artificial Channels	1	Very low	Irrigation ditches and pipes partially filled.
	2	“	
	3	Low	Channels lined with concrete.
	4	“	
	5	Middle-low	Channels lined with masonry.
	6	“	
	7	Middle-high	Excavated channels (without coat).
	8	“	
Natural Channels	9	High	Natural channels consolidated.
	10	“	
	11	Very high	Natural channels without consolidate (in avenues).
	12	“	

Source: self made.

Table 12. Classification of open channels according to roughness categories.

K (roughness category)	**TREND LINE**	**r^2** (coefficient of determination or critic)	**F** (Snedecor statistic)
1	$\lambda = 0.0026 \cdot R^{-0.2430}$	0.9951	11711.2
2	$\lambda = 0.0032 \cdot R^{-0.2691}$	0.9962	15046.2
3	$\lambda = 0.0040 \cdot R^{-0.2952}$	0.9963	15526.5
4	$\lambda = 0.0048 \cdot R^{-0.3112}$	0.9963	15598.9
5	$\lambda = 0.0062 \cdot R^{-0.3308}$	0.9960	14263.3
6	$\lambda = 0.0080 \cdot R^{-0.3545}$	0.9942	10010.6
7	$\lambda = 0.0102 \cdot R^{-0.3665}$	0.9944	10226.5
8	$\lambda = 0.0133 \cdot R^{-0.3914}$	0.9922	7333.24
9	$\lambda = 0.0197 \cdot R^{-0.4166}$	0.9899	5673.76
10	$\lambda = 0.0268 \cdot R^{-0.4222}$	0.9901	5820.31
11	$\lambda = 0.0364 \cdot R^{-0.4322}$	0.9898	5629.16
12	$\lambda = 0.0514 \cdot R^{-0.4384}$	0.9902	5834.41

Source: self made.

Table 13. Potential adjustment of the function $\lambda = f(R)$ for each category of roughness.

3.1.- BACKGROUND

Prior to the proposal of a methodology that is sufficiently valid in the establishment of new alternative formulations for the hydraulic calculation of pressure pipes, it is convenient to carry out –although briefly due to understandable space limitations- a bibliographic review that, in the end, puts I manifest the need to obtain new practical formulas in the face of the disparity of results offered by the application to the real cases of many of the existing ones.

And so, let us see that H. Darcy (1865) carried out extensive experiences on 21 pipes of cast iron, lead, soft iron, asphalt cast iron and glass, with diameters between 0.012 and 0.5 m and 100 m in length (except the glass). Three piezometers made it possible to simultaneously read the pressures in the center and at the ends of the tube. Thus, Darcy found, for new cast tubes, the relationship:

$$D\cdot J = \left(0.001014 + \frac{0.00002588}{D}\right)V^2 \; . \; . \; . \qquad (1)$$

or, expressing the unit head loss as a function of the flow Q, in m^3/s:

$$J = \left(0.001644 + \frac{0.000042}{D}\right)\frac{Q^2}{D^5} ,$$

whose value, thus calculated, of the pressure drop is doubled in the case of used tubes; In addition, when projecting pipes, the diameter D calculated by formula (1) will be increased by twice the thickness of possible incrustations. Since J is approximately proportional to 1: D^5, if that magnitude is doubled, the diameter is only divided by 1.15.

The great disparity of existing criteria among hydraulists regarding this issue, decided the Association of German Architects and Engineers to compile experiences regarding the loss of load and its variation after prolonged service of the pipeline. Data came from many cities, from which O. Iben [2] shortly afterwards deduced that, for clean pipes, Darcy's formula is the one that best expressed the experimental results, and is still applicable for the largest diameters (Forchheimer, 1935-1950). They concluded that no general law can be established for the increase in resistance over time due to the variety and irregularity of the sediments that are deposited on the tube walls (rust, mud, mollusk shells, etc.).

Subsequently, H. Lang in Hütte [3] (1931), taking into account all the experiences published up to 1887 and another 300 of his own, deduced an expression, for speeds between 0.004 and 53 m/s, and for smooth tubes (iron sweet, obtained by pressing or stretching, of glass, of zinc plate, painted or asphalted internally Later, Lang himself modified his points of view, and in 1915 proposed, for turbulent movement in tubes, another formula depending on the Kinematic viscosity.

Analogous results to those of Reynolds (1903) had been reached by A. Flamant (1891), who, based on the essays by Couplet, Jardine, Bossut, Dubuat, J. Leslie, J. Simpson, H. Darcy, GH Bailey, GS Greene, JM Gale, CJN Lampe, CG Darrach, V. Ehmann, O. Iben, Hamilton Smith, FP Stearns, C. Herschel, CB Brush, EC Clarke, Humblot, and Meunier established various formulas (Forchheimer, 1935-1950). However, Flamant seems to be unaware of the greater accuracy achieved by changing $V^{1.75}$ to V^2 in the case of tubes with a very rough internal surface.

While, according to Tutton (Forchheimer, 1935-1950), η decreases when μ increases in the Flamant formulation:

$$V = \lambda D^{\mu} J^{\eta} = \lambda D^{\frac{5}{7}} J^{\frac{4}{7}} \quad \text{ó} \quad DJ = \frac{a_1}{\sqrt[4]{DV}} V^2 ,$$

according to A. V. Saph and E. W. Schoder (1903) they are in a fixed relationship. These authors, by exact measurements on very smooth brass tubes from 2.5 to 52 mm, verified that two apparently identical tubes can give rise to different pressure drops or flow rates, *ceteris paribus*.

E. Sonne maintains the not unjustified view that only a formula for clean or new pipes can be established. He observes that, for diameters of 0.10 and 0.15 m, the head losses measured by O. Iben (1880) are much greater than those calculated according to Darcy's formulas for new pipes, which for D = 0.30 m the tests sometimes offer values higher and others lower than those calculated by said Darcy formula, and that for D = 0.50 m there is no longer any appreciable difference between the calculated and observed values. He points out, among other points, that, according to Lang (1931), the values of J, for tubes of small diameter, are even lower than according to Darcy, and, finally, he proposes the same formula:

$$D \cdot J = \left(0.00087 + \frac{0.00012\sqrt{D} + 0.00003}{D} \right) V^2 = bV^2,$$

which, put under the classic form of Chèzy: $V = c\sqrt{\frac{DJ}{4}}$, give the following series of values (calculated with greater accuracy than that used by the author of the formula):

D =	0.05	0.10	0.20	0.40	0.60	0.80	1.00	1.20	1.60
c =	44.6	50.8	55.7	59.4	61.0	62.0	62.6	63.1	63.8

whereas, according to Darcy, said values of *c* are, respectively:

51.1 56.0 59.2 60.0 61.4 61.8 62.0 62.2 62.3.

Thus, in the case of used tubes, the Sonne formula (Forchheimer, 1935-1950) must be applied, while for new tubes the pressure loss thus calculated must be multiplied by a certain coefficient whose average value is for:

D = 0.1 0.2 0.4 0.6 0.8 1.0 m.
respectively = 2.0 1.8 1.6 1.4 1.2 1.1.

This difficulty is solved with the formulas proposed by this same author, in which the values of the average speed are affected by variable multiplicative coefficients, depending on the internal diameter of the pipe, depending on whether they are semi-new tubes (α_1) or very new (α_2), the same being true, where appropriate, of the loss of unit load J.

B. Biegeleisen and R. Bukowsky (1942) proposed, as a result of many pipe calculations, a formulation for new and used cast pipes, respectively. And so it could be understood that the speed and flow of the used tubes is only 67%, or 2/3 parts, of those corresponding to the new tubes. Also R. Tillmann (Forchheimer, 1935-1950) establishes, for new iron tubes, a new formulation.

Subsequently, as of the second half of the 20th century, the most common employment formulations whose comparison continues to offer disparate results in engineering practice have been the following: Darcy-Weisbach, Hazen-Williams, Manning-Strickler-Gaukler, Scimemi , Meyer-Peter, Ludin, Stucky, Scobey, Kütter, Blasius-Flamant, Kozeny, Cruciani-Margaritora, Veronese-Datei, various modern PVC formulas and others of lesser use, such as those of Dupuit, Lévy, Bazin, Prony, Mougnie , Sonier, Barnes, Vallot, Lang, Von Mises, Biel, Sonne, Colombo, Catani, Wegmann-Aeryns, Eytelwein or Lampe. In all these cases we will omit the expansion and development of each of them for the reasons of space mentioned.

Roughness degree (K)	Material	K_1	β
1	Plastics, glass, brass	86.85	0.62150
2	Asbestos cement, aluminum	78.29	0.63455
3	Steel, other metals	70.02	0.64760
4	Foundry	63.92	0.65560
5	Concrete	56.24	0.66540
6	Ceramics	49.51	0.67725

Source: self made.

Table 15. Coefficients of the proposed formulation according to the different categories of roughness.

Friction coefficients - Normal wear					
Values (D)	**K_0**	**K_1**	**K_2**	**α_1**	**α_2**
0.01	0.833333	1.000000	1.250000	1.200000	1.500000
0.02	1.559038	1.846990	2.265409	1.184699	1.453082
0.03	2.228147	2.616864	3.169873	1.174458	1.422650
0.04	2.857143	3.333333	4.000000	1.166667	1.400000
0.05	3.454915	4.008936	4.774575	1.160357	1.381966
0.06	4.027121	4.651531	5.505103	1.155051	1.367007
0.07	4.577706	5.266523	6.199352	1.150472	1.354249
0.08	5.109583	5.857864	6.862915	1.146447	1.343146
0.09	5.625000	6.428571	7.500000	1.142857	1.333333
0.10	6.125741	6.981019	8.113883	1.139620	1.324555
0.20	10.557281	11.803399	13.383054	1.118034	1.267661
0.30	14.316767	15.827417	17.694468	1.105516	1.235926
0.40	17.660738	19.371294	21.448744	1.096856	1.214487
0.50	20.710678	22.581381	24.823584	1.090326	1.198589
0.60	23.536857	25.540682	27.917451	1.085136	1.186116
0.70	26.184669	28.302039	30.791969	1.080863	1.175954
0.80	28.685614	30.901699	33.488856	1.077254	1.167444
0.90	31.062690	33.365876	36.037961	1.074146	1.160169
1.00	33.333333	35.714286	38.461538	1.071429	1.153846
1.10	35.511161	37.962220	40.776719	1.069022	1.148279
1.20	37.607060	40.121834	42.997033	1.066870	1.143323
1.30	39.629907	42.202985	45.133391	1.064928	1.138872
1.40	41.587058	44.213804	47.194746	1.063163	1.134842
1.50	43.484692	46.161094	49.188557	1.061548	1.131169
1.60	45.328063	48.050615	51.121116	1.060063	1.127803
1.70	47.121683	49.887299	52.997789	1.058691	1.124701
1.80	48.869465	51.675409	54.823199	1.057417	1.121829
1.90	50.574826	53.418657	56.601361	1.056230	1.119161
2.00	52.240775	55.120302	58.335789	1.055120	1.116672
2.10	53.869976	56.783225	60.029580	1.054079	1.114342
2.20	55.464803	58.409984	61.685482	1.053100	1.112155
2.30	57.027383	60.002867	63.305944	1.052176	1.110097
2.40	58.559628	61.563929	64.893160	1.051303	1.108155
2.50	60.063268	63.095023	66.449109	1.050476	1.106319
2.60	61.539873	64.597828	67.975578	1.049691	1.104578
2.70	62.990872	66.073872	69.474190	1.048944	1.102925
2.80	64.417572	67.524548	70.946423	1.048232	1.101352
2.90	65.821171	68.951132	72.393631	1.047553	1.099853
3.00	67.202771	70.354796	73.817052	1.046903	1.098423

Table 17. Absolute and relative coefficients of friction. Normal wear.

NOTE: JUSTIFICATION OF THE VALUES OF THE FRICTION COEFFICIENTS

Under normal operating, conservation and aging conditions, the following values of the coefficient **m** of the Kütter formula are proposed:

$$\begin{cases} \text{Used pipes} & \rightarrow \mathrm{m} = 0.25 \\ \text{Semi-new pipes} & \rightarrow \mathrm{m} = 0.20 \\ \text{New pipes} & \rightarrow \mathrm{m} = 0.15 \end{cases}$$

With this, and based on the diameter D (m), the absolute coefficients of friction previously tabulated will be worth:

- **Used pipes:** $\mathrm{K}_0 = \dfrac{100 \cdot \mathrm{R}}{0.25 + \sqrt{\mathrm{R}}} = \dfrac{25 \cdot \mathrm{D}}{0.25 + \dfrac{\sqrt{\mathrm{D}}}{2}} = \dfrac{50 \cdot \mathrm{D}}{0.50 + \sqrt{\mathrm{D}}}$
- **Semi-new pipes:** $\mathrm{K}_1 = \dfrac{100 \cdot \mathrm{R}}{0.20 + \sqrt{\mathrm{R}}} = \dfrac{25 \cdot \mathrm{D}}{0.20 + \dfrac{\sqrt{\mathrm{D}}}{2}} = \dfrac{50 \cdot \mathrm{D}}{0.40 + \sqrt{\mathrm{D}}}$
- **New pipes:** $\mathrm{K}_2 = \dfrac{100 \cdot \mathrm{R}}{0.15 + \sqrt{\mathrm{R}}} = \dfrac{25 \cdot \mathrm{D}}{0.15 + \dfrac{\sqrt{\mathrm{D}}}{2}} = \dfrac{50 \cdot \mathrm{D}}{0.30 + \sqrt{\mathrm{D}}}$

In the same way, and in relation to the speed and flow rate of the water in the tubes used, the following relative coefficients of friction will be obtained depending on the inside diameter of the tubes:

- For semi-new tubes → $\alpha_1 = \dfrac{\mathrm{K}_1}{\mathrm{K}_0} = \dfrac{0.50 + \sqrt{\mathrm{D}}}{0.40 + \sqrt{\mathrm{D}}}$
- For new tubes → $\alpha_2 = \dfrac{\mathrm{K}_2}{\mathrm{K}_0} = \dfrac{0.50 + \sqrt{\mathrm{D}}}{0.30 + \sqrt{\mathrm{D}}}$

which have been tabulated for the inner diameter series $\mathrm{D} \in (0.01, 3.00)$.

Values of		Used pipes (l/s)						
J (‰)	**D (m)**	**Biel**	**Biegeleisen-Bukowsky**	**Darcy**	**Kütter**	**Hazen-Williams**	**Franquet**	**Average flow**
0.1	0.04	-	0.035	0.044	0.028	0.035	**0.039**	0.036
	0.10	-	0.37	0.49	0.39	0.39	**0.45**	0.42
	1.00	231	142	172	231	166	**202**	191
2.154	0.04	0.176	0.177	0.202	0.130	0.184	**0.182**	0.175
	0.10	2.26	1.88	2.28	1.79	2.04	**2.08**	2.06
	1.00	1110	716	799	1070	872	**939**	918
46.42	0.04	0.91	0.89	0.94	0.60	0.96	**0.85**	0.86
	0.10	11.0	9.5	10.6	8.3	10.7	**9.6**	9.9
	1.00	5200	3604	2950	4980	4579	**4359**	4279
1000	0.04	4.31	4.50	4.36	2.79	5.06	**3.92**	4.16
	0.10	50.7	47.8	49.2	38.6	56.3	**44.7**	47.9
	1.00	24200	18100	13700	23100	24030	**20230**	20560

NOTA: In the case of the Biel (1907) formula, the two uncalculated values are below the lower limit of application or validity of said formula. Own elaboration.

Table 18. Comparison of the six formulations analyzed in cast iron pipe in service.

Values of		Used pipes (l/s)						
J (‰)	**D (m)**	**Biel**	**Biegeleisen-Bukowsky**	**Darcy**	**Kütter**	**Hazen-Williams**	**Franquet**	**DM**
0.1	0.04	-	-0.001	+0.008	-0.008	-0.001	**+0.003**	0.004
	0.10	-	-0.05	+0.07	-0.03	-0.03	**+0.03**	0.04
	1.00	+40	-49	-19	+40	-25	**+11**	31
2.154	0.04	+0.001	+0.002	+0.027	-0.045	+0.009	**+0.007**	0.015
	0.10	+0.20	-0.18	+0.22	-0.27	-0.02	**+0.02**	0.15
	1.00	+192	-202	-119	+152	-46	**+21**	122
46.42	0.04	+0.05	+0.03	+0.08	-0.26	+0.10	**-0.01**	0.09
	0.10	+1.1	-0.4	+0.7	-1.6	+0.8	**-0.3**	0.8
	1.00	+921	-675	-1329	+701	+300	**+80**	668
1000	0.04	+0.15	+0.34	+0.20	-1.37	+0.90	**-0.24**	0.53
	0.10	+2.8	-0.1	+1.3	-9.3	+8.4	**-3.2**	4.2
	1.00	+3640	-2460	-6860	+2540	+3470	**-330**	3217
Nº *outliers*		6	5	6	10	4	**0**	-

NOTE: Shaded amounts indicate the outliers for each formula. DM = Mean Deviation. Own elaboration.

Table 19. Discrepancies of the formulations analyzed in cast iron pipe in service.

Values of		TYPED FLOW VARIABLE *Y*							
J (‰)	**D (m)**	**Biel**	**Biegeleisen-Bukowsky**	**Darcy**	**Kütter**	**Hazen-Williams**	**Franquet**	**Mean**	**Variance**
0.1	0.04	-	-0.25	1.60	-1.60	-0.25	0.50	0	1
	0.10	-	-1.10	1.85	-0.75	-0.75	0.75	0	1
	1.00	1.21	-1.49	-0.50	1.21	-0.76	0.33	0	1
2.154	0.04	0.05	0.09	1.18	-2.05	0.41	0.32	0	1
	0.10	1.11	-1.00	1.29	-1.40	-0.11	0.11	0	1
	1.00	1.37	-1.44	-0.85	1.10	-0.33	0.15	0	1
46.42	0.04	0.41	0.29	0.66	-2.15	0.83	-0.04	0	1
	0.10	1.02	-0.43	0.75	-1.72	0.70	-0.32	0	1
	1.00	1.18	-0.86	-1.70	0.90	0.38	0.10	0	1
1000	0.04	0.21	0.49	0.29	-1.94	1.29	-0.34	0	1
	0.10	0.52	-0.02	0.24	-1.71	1.55	-0.58	0	1
	1.00	0.97	-0.65	-1.82	0.67	0.92	-0.09	0	1
Absolute value Σ		8.05	8.11	12.73	17.20	8.28	3.63	-	-

Source: self made.

Table 20. Typified flow variable.

Values of		95% CONFIDENCE LEVEL						
J (‰)	D (m)	Biel	Biegeleisen-Bukowsky	Darcy	Kütter	Hazen-Williams	Franquet	acceptations
0.1	0.04	-	YES	NO	NO	YES	YES	3
	0.10	-	YES	NO	YES	YES	YES	4
	1.00	NO	NO	NO	NO	NO	YES	1
2.154	0.04	YES	YES	NO	NO	YES	YES	4
	0.10	YES	YES	NO	NO	YES	YES	4
	1.00	NO	NO	YES	YES	YES	YES	4
46.42	0.04	YES	YES	YES	NO	YES	YES	5
	0.10	YES	YES	YES	NO	YES	YES	5
	1.00	NO	YES	NO	YES	YES	YES	4
1000	0.04	YES	YES	YES	NO	NO	YES	4
	0.10	YES	YES	YES	NO	NO	YES	4
	1.00	YES	YES	NO	YES	YES	YES	5
nº *outliers*		3	2	7	8	3	0	47

Source: self made.

Tabla 21. Classification according to the 95% confidence level.

Materials and procedure used in the experimental test

Firstly, the pipeline object of our study had to be chosen, determining the following factors: material of which it was made, internal diameter (in the case of being external, the interior had to be determined by the thickness of the wall, measured with vernier caliper), length and special pieces.

It was also necessary to determine the characteristics of the fluid (drinking water) that circulates inside it and the temperature (which turned out to be 19ºC in all three cases), since kinematic viscosity, as is known, is a function of temperature.

It was also necessary to apply the flowmeter to each pipe to determine, at all times, the amount of fluid that was circulating through the section analyzed. For this, a Dostmann flowmeter, model P-770-M, manufactured by PCE Instruments was used, which also offered the centigrade temperature through a liquid crystal display (LCD).

Once the flow meter was in place, the gate valves were opened to allow the flow of the fluid until the flow meter indicated the desired flow rate (it must be borne in mind that obtaining specific or discrete data, such as 1 l/s, 2 l/s, ... is very difficult, since this operation is not performed mechanically, but manually).

When the desired fluid passage was obtained, the pressure at the beginning of the pipe and at the end of the pipe was measured by means of an analog glycerin pressure gauge (manometer). To do this, it was necessary, before taking the samples, to calibrate the manometer. In case of presenting a certain margin of error, this will be the same in both the first shot and the second shot, which can affect the specific data but not the difference between data.

The pressure loss obtained so far is that which occurred between the beginning and the end of the pipe. Lastly, to obtain the unit head loss (linear m/m), the relationship between the total head loss and the length of the section of the pipe analyzed had to be calculated, that is: $J = H/l$.

MATERIAL: PEAD

FÓRMULA: MANNING-STRICKLER-GAUKLER

FLUIDO	t (ºC)	ν (m^2/s)	D (m)	e (m)	d (m)	g (m/s^2)	Q (m^3/s)	V (m/s)	n	J (m/m)	l (m)	Hr (mca)	Hr+Hs (mca)	Hreal (mca)	Diferencia (mca)	$\frac{Dif.^2}{Hr + Hs}$ (mca)
Agua	19	$1.0444 \cdot 10^{-6}$	0.1250	0.0060	0.1130	9.81	0.0031	0.3041	0.0075	0.0006	316	0.1911	0.2198	0.5165	-0.2967	0.4005
Agua	19	$1.0444 \cdot 10^{-6}$	0.1250	0.0060	0.1130	9.81	0.0050	0.4986	0.0075	0.0016	316	0.5136	0.5906	1.5495	-0.9589	1.5569
Agua	19	$1.0444 \cdot 10^{-6}$	0.1250	0.0060	0.1130	9.81	0.0098	0.9772	0.0075	0.0062	316	1.9729	2.2668	4.6485	-2.3817	2.5024
Agua	19	$1.0444 \cdot 10^{-6}$	0.1250	0,0060	0.1130	9.81	0.0141	1.4060	0.0075	0.0129	316	4.0840	4.6966	7.7475	-3.0509	1.9819
Agua	19	$1.0444 \cdot 10^{-6}$	0.1250	0,0060	0.1130	9.81	0.0195	1.9445	0.0075	0.0247	316	7.8112	8.9829	13.4290	-4.4461	2.2006
Agua	19	$1.0444 \cdot 10^{-6}$	0.1250	0.0060	0.1130	9.81	0.0236	2.3533	0.0075	0.0362	316	11.4413	13.1575	19.6270	-6.4695	3.1810
Agua	19	$1.0444 \cdot 10^{-6}$	0.1250	0.0060	0.1130	9.81	0.0268	2.6724	0.0075	0.0470	316	14.7543	16.9675	24.7920	-7.8245	3.6082

Diferencia media absoluta: 3.6326 m.c.a. $\chi^2 = 15.4315$ m.c.a.

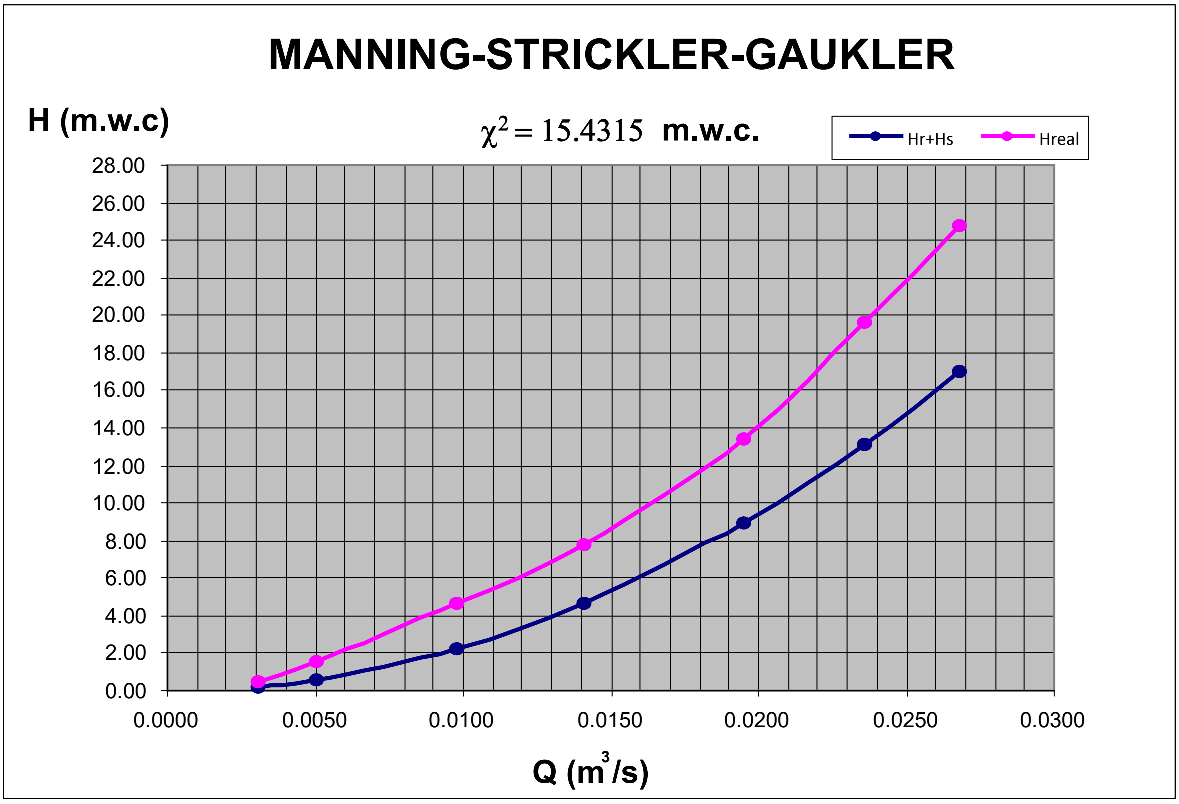


Table and graph 22. Observed differences between theoretical and real pressures.

FORMULA	MAT. PIPELINE	Absolute mean discrepancy	Σ discrep. (m.w.c.)	Order number	χ^2 (m)
Darcy - Weisbach	HDPE	3.2883	7.1275	6	11.0218*
	PVC	0.3757			0.5576
	ASB	3.4635			6.5877**
Blasius – Flamant	HDPE	3.2890	4.9870	2	10.9472*
	PVC	0.4418			0.6845
	ASB	1.2562			0.7423
Manning – Strickler	HDPE	3.6326	16.3789	7	15.4315*
	PVC	0.7108			1.4338
	ASB	12.0355			32.5649*
Kütter	HDPE	1.1048	7.1203	5	2.1137
	PVC	2.3454			8.6678**
	ASB	3.6701			4.6439**
Hazen – Williams	HDPE	3.0870	6.0733	3	9.6981**
	PVC	0.4358			0.6724
	ASB	2.5505			2.4251**
Scobey	HDPE	2.2102	6.1499	4	4.8745**
	PVC	0.7130			1.3545
	ASB	3.2267			3.6613**
Franquet	HDPE	1.5276	4.1719	1	1.7142
	PVC	0.6860			1.3504
	ASB	1.9583			1.6699**

Source: self made.

Table 23. Discrepancies between observed and actual values.

NOTE: Empirical formulations that differ significantly from those observed at the significance level of 0.10 have been indicated in the table above with an asterisk (*), which is the case with the Darcy-Weisbach, Blasius-Flamant and Manning-Strickler formulations. Gaukler [17], for the HDPE, and also for the latter in the case of the ASB. It may happen, however, that the agreement between the two distributions is not so good as not to reasonably doubt what was deduced, or that the results obtained empirically are subject to a reasonable influence of sampling error, for which reason the study should also be carried out of the probability distribution $\chi^2_{0.10}$ in all cases, having indicated with a double asterisk (**) those somewhat dubious formulations, in this latter sense.