FLOW CHARACTERISTICS OF RICE GRAINS IN GRAVITY PIPES

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ABSTRACT

To study the parameters affecting the fluidity of rice by gravity pipe system in order to improve the design of the gravity pipes in an effective and economical way. Two paddy rice Sakha 103 as a short variety, and Jasmine local aromatic as a long variety was selected for this study. The rice samples were prepared for gravity flow experiments by mechanically cleaned. The fresh and clean paddy samples were naturally drying until 14 (M.C.w.b. %).Physical characteristic tests of paddy rice grains and its products (brown and white), were conducted including grains dimensions, aspect ratio, grains volume, surface area, equivalent diameter, sphericity, weight of 1000 grains, bulk density, particle density, porosity, grain hardness, angle of repose and static coefficient of friction on galvanized sheet.Flowability experiments of rice grains were conducted in three main groups, first throughout orifice, second through orifice and elbows and third throughout orifice, elbows and pipe.

Keywords: *Rice, Physical characteristic, Gravity, Pipes, Inclination, Orifice, Elbows.*

1. INTRODUCTION

Gravity flow has important applications in the grains processing industry and post harvest technology. Gravity pipes are an integral part of all conveying and handling systems they are relatively cheap, effective and maintenance free. In Egypt most rice and wheat mills are going to expansion in vertical construction and that is because high cost and low availability of ground area. So tend to use vertical and inclined pipes to handling materials. The main factors governing the process of grains gravity flow inside tube can be classified into three parts as follow:

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1- Pipe materials, dimensions and inclinations.
2- Grains type and variety and their physical characteristics including dimensions, surface roughness, texture, moisture content and density.
3- Climate condition surrounding the process as a temperature and relative humidity.

Physical dimensions, and particle dimensions distribution, both play significant roles in flowability and other properties, such as bulk density, angle of repose, and compressibility of bulk solids.

Even a small change in particle size can cause significant alterations in the resulting flowability. Reduction in particle size often to increase the flowability of a given granular material until it reach a critical point the flowability decreased with reducing particle size due to the increased surface area per unit mass. (Fitzpatrick J J; Barringer S A; Iqbal T , 2004).
Flow ability of agricultural grains is usually measured using the angle of repose. This is a measure of the internal friction between grains and can be useful in hopper design, since the hopper wall's inclination angle should be greater than the angle of repose to ensure the continuous flow of the materials by gravity. (Ghasemi varnamkhasti et al., 2008).
The proper design of grain handling equipment requires knowledge of its frictional characteristics. The force of friction must be overcome before these materials will flow from hoppers and pipes.
Bins, hoppers, orifices, pipes, and elbows constitute major items of equipment in the handling of granular materials.
Moysey et al. (1985), Chang et al. (1985) and J. M. Gregory and C. B. Fedler, (1987), show the form of predicted equation to describe granular flow through orifices as follow.

$$Q = g \frac{\pi \ D^3}{16} \frac{{\rho_b}^2}{k} \qquad (1)$$

Where: Q = mass flow rate ,ρ_b = bulk density of material, g = acceleration due to gravity, D= diameter of the orifice, The coefficient (k) is a unique variable that depends on the physical properties of the granular material.
Pipe flow under gravity is used for a lot of purposes. Various physical parameters of gravity pipes such as gravity pipe diameter, the inclination of the gravity pipe. Trees (1962) found that the flow out of the pipe

stopped when the angle of pipe inclination to the horizontal approached the angle of repose of the particulate material. Doron et al. (1996) studied the effect of inclination on the characteristics of slightly inclined tubes (up to 7°). They reported a considerable effect of the inclination on the flow characteristics.

For a long pipeline, the length produces resistance to the flow by frictional resistance at the pipe wall. Note that even for smooth pipes the friction factor is not zero. That is, there is a head loss in any pipe, no matter how smooth the surface is made. This is a result of the no-slip boundary condition that requires any materials to stick to any solid surface it flows over.

Sarkar et al. (1991) also found that the solids flow rate through a sufficiently long pipe approached zero when the angle of inclination approached the angle of repose of the material.

Avery few researches have talked about the effect of pipe diameter on the grains flow rate throughout gravity pipe handling system, e.g. (Shanahan, C.E., Schwarz, J., (1954)., Trees, J., (1962)., Sarkar, M, et al., (1991), and A.J. Tamara et al. (2006)) and this indicates that a lack of information in this area, in spite of major importance and the direct impact of the pipe diameter effect on the granular flow rate.

A.J. Tamara, C.Yap, M.A. Mannan (2006). Clarify that the process of selecting gravity pipe diameter usually based on the diameter outlet of the bins or the inlet of the feeder.

2. MATERIALS AND METHODS

Two paddy rice varieties of the most spreading in Egypt were selected, Sakha 103 as a short variety, and Jasmine local aromatic as a long variety. An amount of 500 kilograms of each paddy rice variety were obtained of the 2015 crop from the experimental farm of Rice Research Training Center (RRTC) at Sakha Kafer-Elsheikh governorate. The rice samples were prepared for gravity flow experiments by mechanically cleaned to remove foreign materials such as straw, soil particles, mud balls and weed seeds according to the different shape, size and specific weight. Cleaning was done by electric apparatus; namely, Carter-Day Dockage Tester model (TGR). The paddy was then sorted by testing thickness grader model (TWS). Immature rough rice grains of less thickness than 1.6 mm are separated out through 1.6 mm slot mesh sieves. Sample moisture content was measured instantaneously using electric resistance moisture meter (PB1D. The fresh and clean paddy samples were naturally drying until the moisture content reached to about 14 (M.C.w.b. %).

All experimental tests and setup were done in rice technology training center (RTTC) in El Awaied, Alexandria, Egypt.

Physical properties test of paddy rice grains and its products (brown and white), were conducted including grains dimensions, aspect ratio, grains volume, surface area, equivalent diameter, sphericity, weight of 1000 grains, bulk density, particle density, porosity, grain hardness, angle of repose and static coefficient of friction on galvanized sheet.

Gravity flow experimental setup (fig. 1) was designed and constructed to evaluate the flowability of rice grains and their products by gravity through different parts of the system. The experimental unit was constructed which suitable for samples of 75 kg of paddy up till 150 kg of white rice.

Figure (1): shown experiment set up to 8 cm diameter pipe with 1 m length and 90° vertical angle**.**

The constructed system consists of the following parts:

1- Sample tank made of 1.5 mm galvanized sheet as a cube-shaped with inside dimensions of 50 cm, with frustum of a pyramid bottom with inclination angle of 45º and the base is a square of 20 cm side dimensions.
2- Reduction joint used to connect the tank bottom with the orifice, elbows and pipes.
3- Four elbows are designed to make the inclination angle of 75, 60, 45 and 30º on the horizontal for each pipe diameter, each elbow design in order to give 15 degree of inclination.
4- Three pipes diameters of 6, 8 and 10 cm were prepared to used with three pipes length of 0.5, 1.0 and 1.5 meters.
5- Three clamps with different sizes depending on the pipe diameter is used (10- 8- 6 cm) to fix the tank with the reducing joint and to fix it with the required pipe.
6- Three sliding gate was designed to control the rice flow by pipes one for each pipe diameter and was fixed on the end of the pipe.
7- Steel frame is constructed to carry the setup with the dimensions of 2.0 x 0.58 x 0.58 meters for each of height, width and breadth respectively. The tank is installed in the upper end of the frame.

2.1 Experimentation and Procedure:

Six rice samples include two rice varieties Sakha 103 and local Jasmine and three rice products paddy, brown and white were tested.

Flow ability experiments of rice grains were conducted throughout three groups of experiments as follow:

1- The first group of the experimental tests is the study of the effect of horizontal orifice on the flow rate of rice grain. A sliding gate amounted outside the test orifice was used to control the start and stop of a given test. The experimental tests were including 90 tests, three orifice diameters (6, 8 and 10 cm), two rice variety (Sakha 103 and Local Jasmine), three products of rice (paddy, brown and white rice) and five replicates.

2- The second group of the experimental tests is the effect of the combination of the horizontal orifice and elbows on the flow rate of rice grain which are conducted and including 360 tests. The experiments include three diameters (6, 8 and 10 cm), four inclinations (15, 30, 45 and

60° on the vertical plane), two rice variety (Sakha 103 and Local Jasmine), three products of rice (paddy, brown and white rice) and five replicates. The experiments will show reduction in flow rate due to elbow resistance.

3- The third group of experimental tests is the effect of the combination of horizontal orifice, elbows and pipes on the flow rate (Qoep, kg/sec) of rice grain which were conducted and including 1350 tests. The experiments include three diameters (6, 8 and 10 cm), three pipe length (0.5, 1.0 and 1.5 m), five inclinations (0.0, 15, 30, 45 and 60° on the vertical plane), two rice variety (Sakha 103 and Local Jasmine), three products of rice (paddy, brown and white rice) and five replicates.

In every flow ability experiments the sample tank were filled to the head level with test rice grain and then the sliding gate opened to allow grain to flow through the system to a receiving bucket below the opening. After test completion, grain collected in the bucket was weighted and returned to the tank for replication. Grain weight and flowing time were recorded and used to determine the mass flow rate of grain for each test.

The paddy grain after the finishing of all physical characteristics tests and flowability experiments for each of Jasmine and Sakha 103 paddy variety were then introducing to Satake One-Pass Rice Pearler : Milltop SB10D to get brown grains. Then after doing all the experiments on brown grains we use the same machine again for whitening grains to complete the experimental study.

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics of Rice Grains.

The summary of the physical characteristics data of paddy, brown and white rice grains as average values of the two selected rice varieties Sakha103 as a short grains and Jasmine local aromatic varieties as long grains are present in table (1).

3.2 Flow Characteristic of Rice Grains in Gravity Pipe System.

The total of 1800 experimental gravity flow test's which includes three experimental groups. The first group is the test of the horizontal orifice's which include 90 experimental tests. The second group is the test of the combination of orifices and elbows and includes360experimental tests. The third and main group is the test of the combination of orifices, elbows and pipes and include 1350 experimental test.

Table (1): Physical Characteristics of Rice Grains

Rice Grains Physical Characteristics	Paddy Jasmine	Paddy Sakha	Brown Jasmine	Brown Sakha	White Jasmine	White Sakha
Length, (Lg) mm	9.93	7.68	6.89	5.36	6.72	5.03
Width, (W) mm	2.57	3.25	1.95	2.65	1.89	2.45
Thickness, (T) mm	1.78	2.125	1.443	1.741	1.375	1.632
Aspect Ratio, (Ra)	3.861	2.358	3.521	2.028	3.546	2.049
Arithmetic mean diameter,(da), mm	4.768	4.355	3.428	3.260	3.328	3.037
Geometric mean diameter,(dg), mm	3.575	3.758	2.686	2.909	2.592	2.712
Equivalent diameter , (de), mm	3.616	3.817	2.707	2.953	2.616	2.754
Sphericity, (Ø)	0.359	0.489	0.390	0.544	0.386	0.540
Surface area, (S), mm^2	37.58	38.33	20.68	22.7	19.33	19.69
Grain volume, (V), mm^3	24.86	29.23	10.42	13.71	9.40	11.03
Moisture Content,(wb %)	12.643	13.080	13.305	13.772	13.769	13.943
Weight of 1000 grains(W_{1000}) , g.	26.17	26.87	22.10	23.92	20.55	21.80
Bulk density, (ρ_b) kg/m^3	548	573	805	860	820	904
Particle density,(ρ_p) kg/m^3	754	822	1059	1037	1094	1089
Porosity, (ε), %	29.2	30.3	23.9	17.11	25.05	17.049
Repose Angel, (Θ_r)	32.20	34.57	31.51	32.45	31.05	31.84
Coefficient of internal Friction, μi	0.63	0.69	0.61	0.64	0.60	0.62
Friction Angel, (α)	21	19	18	17	17	17
Coefficient of surface Friction, μs	0.38	0.34	0.32	0.30	0.30	0.30
Hardness, (F_{th}), kg.	6.40	6.50	6.20	6.30	5.90	6.00

3.2.1 Effect of Horizontal Orifice

The flow rate of all products through the horizontal orifice increased in a logarithmic function with orifice diameter. The flow rate of Sakha 103 variety in general more than the flow rate of Jasmine for all product (paddy, brown and white rice).

The mathematical models and statistical analysis for the effect of horizontal orifice diameter (D) on the rice flow rate were conducted using Moysey's equation.

A multiple regression statistical analysis were conducted to determine the best fit relationship between The equation cefficient (k) and rice grain physical properties include the coefficient of internal friction, coefficient of surface friction, spherecity and mean geometric diameter for each rice variety and rice product. The derived equation of coefficient (k) from statistical regression analysis has been substitute in the Moysey's equation to reach the values of the flow rate of horizontal orifice.

Coefficient (k), $kg/m^2.s = 172.87\ Ø - 130734\ dg + 564.56\ \mu s + 520.55\ \mu i$. . . . ..(2)

$R^2 = 0.99$, STD = 3. 4

So the mass flow rate (Q_o, kg/s) throughout orifice equation will be as following:

$$Q_o = g \frac{\pi\ D^3}{16} \frac{{\rho_b}^2}{(172.87\ Ø - 130734\ dg + 564.56\ \mu s + 520.55\ \mu i)} \quad . . . . . . (3)$$

3.2.2 Effect of Elbows

The results show that mass flow rate of elbows decrease with the increase of angle of inclination on the vertical plane. Mass flow rate is direct proportion with the system diameter. The results clarify also that the white rice has the maximum flow rate comparing with brown and paddy. The paddy rice flow rate has the minimum value that is due to the surface friction properties of the different rice products paddy, brown and white rice.

The mass flow rate through elbows (ΔQe) can determined by subtracts the flow rate of the combination of orifice and elbows (Qoe) from the flow rate of orifice only (Q_o).

$$\Delta Qe = Qo - Qoe \quad . . . . . (4)$$

A multiple regression statistical analysis were conducted to determine the best fit relationship between flow rate loss due to elbow and elbow parameters include circumference length, diameter and inclination angle, material parameters include mean geometric diameter, sphericity, bulk density, coefficient of internal friction and coefficient of surface friction.

Non linear logarithmic regression statistical analysis was determined in order to describe the relationship between elbow flow rate and each of elbow's and grain parameters.

$$\Delta Q \text{ elbow} = \frac{d_g^{3.723}\ \rho_b^{3.12}\ D^{4.82}\ \theta^{1.56}}{\varnothing^{1.44}\ \mu_i^{2.16}\ \mu_s^{2.34}\ \lambda^{0.804}} \ldots R^2 = 0.99,\ STD = 0.0686 \ldots (5)$$

Note that inclination, θ in the equation measured to the vertical and λ is the elbow circumference length.

3.2.3 Effect of Pipes

The results clarify in general that for all samples the rice flow rate through pipes decrease with the increase of inclination on the vertical direction, and vice versa, the flow rate directly proportional to the diameter and inversely proportional to the length of the pipe. The results clarify that the drop in flow rate due to the pipe length is directly proportional. The drop in flow rate increases with pipe length with decreasing rate in a logarithmic function. The flow rate of Sakha 103 variety is more than local Jasmine paddy rice variety for all products.

The flow rate of rice product mainly depends on the physical characteristic of different rice samples and the specification of the gravity flow system. The main physical characteristic parameters affecting the flow rate are surface friction (**μ_s**), surface area (S mm^2), weight of 1000 grains (W_{1000} gr.) and spherecity (Φ). The author used the later physical characteristic parameter to produce a flow index named flowability factor (ξ) which can help in describing the flow phenomena of different grain sample.

$$\xi = \frac{\mathbf{1000} * \varnothing}{\mu s * \mathbf{S} * \mathbf{W1000}} \ldots (6)$$

The results table (2) clarify that the maximum flowability factor was for white rice Sakha103 variety The comparisons of flow rate for different products agree with the values of the calculated flowability factor (ξ), which the maximum flow rate corresponds to the maximum flowability factor.

Table (2) : Friction factor of rice products

Rice product	**μ_s**	**S , mm^2**	**W_{1000}, gr**	**Ø**	**factor (ξ)**
Paddy Sakha103	0.34	38.33	26.87	0.489	1.396
Brown Sakha103	0.30	22.70	23.92	0.544	3.339
White Sakha103	0.30	19.69	21.80	0.540	4.193
Paddy Jasmine	0.38	37.58	26.17	0.359	0.960
Brown Jasmine	0.32	20.68	22.10	0.390	2.666
White Jasmine	0.30	19.33	20.55	0.386	3.239

Non linear logarithmic regression statistical analysis were conducted to determine the best fit relationship between flow rate loss due to pipe (ΔQp) and each of pipe parameters include pipe length (L), pipe diameter (D) and pipe inclination angle on the horizontal (θ_h), and grain parameters include mean geometric diameter (dg), sphericity (Ø), bulk density (ρ_b), coefficient of internal friction (µi) and coefficient of surface friction (µs). The analysis drive us to the best fit equation which can describe the relationship between flow rate loss due to pipe (ΔQ pipe) and each of pipe and grains parameters.

$$Qoep = Qo - \Delta Qe - \Delta Qp \; . . . . (7)$$

$$\Delta Q \text{ pipe} = \frac{d_g^{2.67} \; \mu_i^{1.47} \; \rho_b^{3.44} \; D^{3.66} \; L^{0.479}}{\emptyset^{1.44} \; \mu_s^{1.098} \; \theta_h^{0.159}} \; . . . . (8)$$

$R^2 = 0.99$, ST.D = 0.07119

Note that inclination angle (θ_h) was measured to the horizontal.

Measured mass flow rate data and predicted values using equations (7), (3), (5) and (8) for all rice samples were demonstrated in figures 4-16 to 4-21. The predicted values were very close for all measured data.

The results of measured mass flow rate data and predicted values were very close for all rice samples. The results showed that the derived equations represented the results obtained significantly. (fig.2).

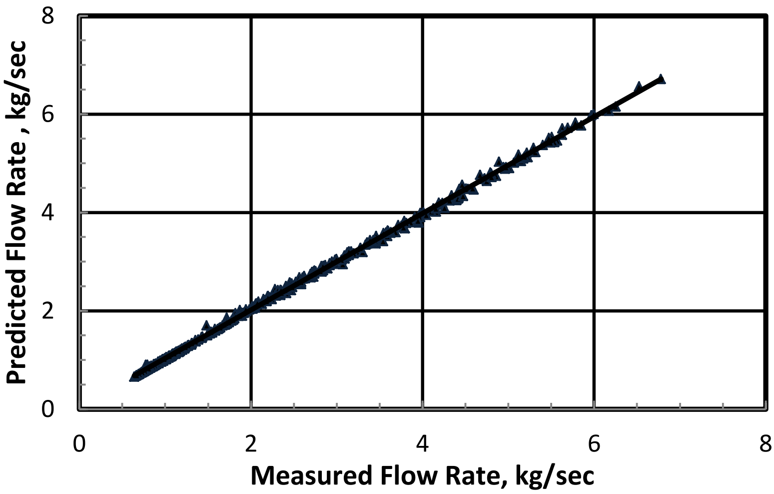

Figure (2): Verification of measured mass flow rate data and predicted mass flow rate for all rice samples.

In order to verify the mathematical model, the statistical regression analysis was conducted between the measured flow rate as an independent variable and the predicted flow rate as a dependent variable. The statistical equation have shown without the slightest doubt that the mathematical model that we have developed has succeeded greatly in the description of the behavior of the flow characteristics of grain under study.

$$Q_P = 0.055012 + 0.981698\ Q_m \quad R^2 = 0.9988 \quad STD = 0.048529 \ \ldots\ldots (9)$$

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الملخص العربى

خصائص سريان حبوب الأرز فى مواسير النقل بالجاذبية

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الهدف من هذا البحث هو دراسة العوامل التي تؤثر على سريان أصناف الأرز ومنتجاته عن طريق الجاذبية باستخدام الأنابيب من الحديد المجلفن وما يلزمها من وصلات و كيعان بأقطار وأطوال وميول مختلفة. هذه الدراسة تساعدنا علي عمل التصميم الأمثل لأنابيب الجاذبية وكذلك في فهم تأثير مختلف العوامل التي تحكم خصائص تدفق المواد الحبيبية.

تم اختيار صنفين من الأرز من أكثر الأصناف انتشاراً في مصر وهو الصنف سخا ١٠٣ وهو من الأصناف اليابانية قصيرة الحبة ، والصنف ياسمين وهو من الأصناف العطرية المحلية طويلة الحبة.

تم اجراء بعض اختبارات الخصائص الفيزيائية علي حبوب الأرز الشعير ومنتجاته (البني والأبيض) وتشمل قياس أبعاد الحبوب وتقدير نسبة طول الي عرض الحبة و حجم الحبوب، والمساحة السطحية للحبوب، وتقدير القطر المكافئ، و الكروية، و وزن ١٠٠٠ حبة، و الكثافة الكمية، و كثافة الحبة، والمسامية، وتقدير صلابة الحبوب ، وتقدير زاوية للراحة وتقدير معامل الاحتكاك على الصاج المجلفن.

تم تصميم وتصنيع الوحدة التجريبية لإجراء الإختبارات المختلفة لاختبارات السريان لحبوب الارز حيث تم إنشاء وحدة تجريبية مناسبة لعينات من ٧٥ كجم من الأرز حتى ١٥٠ كيلو من الأرز الأبيض.

اجمالى مجموع ١٨٠٠ تجربة سريان لحبوب الارز و الذي يتضمن ثلاث مجموعات تجريبية. المجموعة الأولى هي اختبار السريان الخارج من الثقب الأفقي اسفل الخزان التي تشمل ٩٠ اختبار تجريبى. المجموعة الثانية هي اختبار السريان الخارج من التوليفة من الثقب الأفقي والكوع. المجموعة الثالثة هي اختبار السريان الخارج من التوليفة بين الثقب الأفقي والكوع والماسورة وتشمل ١٣٥٠ اختبار تجريبي.

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معدل السريان الخارج من الثقب الأفقي لصنفى و أنواع الارز المختبرة يتناسب تناسب طردي مع قطر الثقب. وكان معدل سريان صنف سخا ١٠٣ فى جميع المنتجات أعلى من معدلات مثيله فى الصنف ياسمين.

تم استخدام معادلة Moysey's لحساب معدل السريان الخارج من الثقب الأفقي. ولقد تم ايجاد معادلة مستنبطة من تحليل الانحدار الاحصائى لوصف العلاقة بين معامل المعادلة والخواص الفيزيائية لحبوب الارز وتشمل معامل الاحتكاك الداخلي ومعامل الاحتكاك السطحى، الكروية ومتوسط القطر الهندسي لكلا صنفى الأرز ومنتجاته.

بينت النتائج أن معدل سريان الحبوب الخارج من الكيعان ينخفض مع زيادة زاوية الميل على الرأسى. وأن العلاقة بين معدل السريان و القطر علاقة طردية. أوضحت النتائج أيضا أن الأرز الأبيض أعطى أعلى معدل سريان مقارنة مع البني والأرزالشعير. معدل السريان للأرز الشعير لديه أقل القيم ويرجع ذلك إلى اختلاف قيم معامل الاحتكاك السطحى بين المنتجات المختلفة للأرز الشعير و البني والأبيض.

الفقد فى معدل السريان الراجع الى الكيعان تم حسابه وتم اجراء التحليل الإحصائي الانحدار المتعدد لتحديد أفضل علاقة بين الفقد فى معدل السريان الراجع الى الكيعان وبين والمعاملات المختلفة والتى تشمل معاملات خاصة بالكوع مثل طول المحيط، القطر وزاوية الميل، و معاملات خاصة بالحبوب وتشمل متوسط القطر الهندسي، الكروية، الكثافة، معامل الاحتكاك الداخلي ومعامل الاحتكاك السطحى.

أوضحت النتائج أن معدلات السريان خلال الأنابيب لجميع عينات الارز تنخفض مع زيادة الميل على الرأسي، والعكس بالعكس، وإن معدل السريان يتناسب طرديا مع القطر ويتناسب عكسيا مع طول الأنابيب.

معدل السريان الناتج يعتمد بشكل رئيسي على الخصائص الفيزيائية لعينات الأرز المختلفة.فمن الخصائص الرئيسية التي تؤثر على معدل السريان معامل الاحتكاك السطحى، المساحة السطحية للحبوب، وزن ١٠٠٠ حبة والكروية.

تم استنباط معامل جديد يسمى بمعامل السريان (ع) يعتمد علي الخصائص الفيزيائية السابقة. وكانت القيم المستنتجة لمعامل السريان توضح أن الأرز الأبيض صنف سخا ١٠٣ له أعلى معامل سريان بقيمة (٤.١٩٣٤)، ثم يليه الأرز البني لصنف سخا ١٠٣ (٣.٣٣٩)، والأرز الأبيض صنف الياسمين (٣.٢٣٩) والأرز البني صنف الياسمين (٢.٦٦٦)، الأرز الشعير صنف سخا ١٠٣ (١.٣٩٦) والأرز الشعير صنف الياسمين (٠.٩٦٠) على التوالي. وبالمقارنة بين قيم معامل السريان المتحصل عليه مع بيانات معدلات السريان للعينات المختلفة كان هناك اتفاق قوي بينهما حيث ان أعلي معامل سريان تم الحصول علية يتوافق مع أقصى معدل سريان للأرز الابيض سخا ١٠٣ وهكذا. وبالتالي يمكن استخدام معامل السريان لفهم وتحليل بيانات معدل السريان لعينات الارز المختلفة ويمكن تعميمة علي كافة الحبوب المختلفة.

أجري التحليل الاحصائى الانحدار المتعدد لايجاد أفضل معادلة توصف العلاقة بين الفقد الراجع الى الانابيب (ΔQp) وكل من المعاملات الخاصة بالأنابيب التى تشمل طول الأنبوب (L)، قطر الماسورة (D) و زاوية الميل على الأفقي (θ_h)، و المعاملات الخاصة بالحبوب والتى تشمل متوسط القطر الهندسي (dg)، الكروية ($Ø$)، الكثافة الظاهرية (ρb)، معامل الاحتكاك الداخلي (μi) ومعامل الاحتكاك السطحى (μs).

تم توقيع النتائج من المعادلات المستنبطة من التحليل الاحصائى مع البيانات المقاسة على رسم بيانى وأظهرت أن المعادلات المستنبطة تمثل البيانات بشكل كبير. ومن أجل التحقق من النموذج الرياضي، أجري تحليل الانحدار الإحصائي بين معدل السريان المقاس كمتغير مستقل ومعدل السريان المتوقع كمتغير تابع. وقد أظهرت المعادلة الإحصائية دون أدنى شك في أن النموذج الرياضي نجح إلى حد كبير في وصف سلوك خصائص سريان الحبوب تحت الدراسة.