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ANALYSIS OF OUTCOMES OF THE FRICTIONAL PRESSURE DROP PREDICTION USING DIFFERENT DATA SOURCE

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Abstract

Predictions of the frictional pressure drop using friction factor correlations that have been developed based on past experimental data have always been found to disagree with recent experimental data. Thus, new correlations are continuously being developed to generalize their applications across refrigerants and flow regimes. The friction factor is dependent on the Reynolds number and relative roughness, therefore consequently depends on the applied equation and fluid data. This research shows the outcome of the analysis of the frictional pressure drop prediction when different data source as well as different friction factor equations for smooth and rough pipes are utilized. The R-22 data used for comparison are experimental data from a past report, NIST (Standard Reference Database), and experimental data from University of Indonesia. The used e friction factor equations are Blasius and Fang *et al*. (2011) in smooth and rough pipe respectively. The mass flux is ranging from 200 to 600 kg/m^{2}s and vapor quality from 0.0001 to 0.5, the latter of which is assumed constant along the pipe length of 2000 mm at the saturation temperature of 10°C. The pipe material is stainless steel with an absolute roughness of 0.03 mm. The minimization of the friction factor and two-phase flow frictional pressure drop is achieved by applying Genetic Algorithm (GA). The comparisons reveal that the differences are an indication of the appropriate data source necessary so that the frictional pressure drop can be accurately predicted. The results showed that in 1.5 mm pipe diameter, the Blasius equation gives the lower percentage of differences in the range of 0.69 – 1.47 % when the data from NIST and UI are used. While the lower percentage of differences gives Fang *et al*. (2011) equation in the range of 1.47 – 2.61% when data from Pamitran *et al*. (2010) and UI are used. In the 3 mm inner diameter, also Blasius equation gives the lower percentage of differences in the range of 0.89 – 2.52% when the data from Pamitran *et al*. (2010) and UI are used. While Fang *et al*. (2011) gives the lower percentage of differences in the range of 1.56 – 1.33% when the data from Pamitran *et al*. (2010) and UI are used. The proposed method is predictable to raise the accuracy of the prediction and decrease the time of testing. The results are compared between each other's for different data sources. For most situations, the percentage difference, as well as for laminar and turbulent flows are between 91 – 97% and 88 – 95% in 1.5 and 3 mm pipe diameter respectively.

Keywords: Two-phase flow, friction factor, pressure drop, Genetic Algorithm

1.0 INTRODUCTION

Accurate prediction of the two-phase flow pressure drop plays an important role for the proper design and optimization of the air-conditioning, refrigeration and heat pump systems. Ould Didi, *et al*., [1] stated that the drop in pressure across the length of a pipe in two-phase flow is accompanied by at most a 1.4°C drop in the saturation temperature, T_{sat}, it is not a constant as has always been assumed.

Pressure drop in pipes can generally be calculated using the Darcy-Weisbach equation. Using this equation requires the Darcy friction factor to be known. The acceptable equation to date for calculation of the Darcy friction factor in the turbulent flow regime is offered by the Colebrook-White equation (often called the Colebrook equation) [2].

However, the solution to the equation can only be obtained through an iterative procedure. Several equations were then developed to overcome this issue. It was found that some of these equations provide accuracy of ±1.5% when compared with the Colebrook equation [3]. This makes it possible to use them instead of the Colebrook equation [4]. Moreover, some researchers have discovered that the Colebrook equation is inadequate for pipes with diameters smaller than 2.5 mm [5].

Zagarola stated that the Colebrook equation in smooth pipes is more accurate at high Reynolds numbers [6]. Many attempts have been made to address the differences between one correlation and another, and to generalize the correlations to be applicable for smooth as well as rough pipes [7]. Many studies have been completed to develop an equation that can be applicable for smooth and rough pipes, turbulent flows, for all ranges of Reynolds number *Re* and roughness factor [8].

Genić, *et al*., did a review on some developed equations of the Colebrook's equation. He found that the most accurate estimate of the friction factor can be obtained using the Zigrang and Sylvester equation [9, 10].

In 2012, Samadianfard examined the use of genetic programming (GP) in estimating friction factor in turbulent flow in comparison with the Colebrook–White equation [11]. He discovered that applying the genetic expression program is more accurate than using the commonly developed equations.

In that same year, Xu, *et al*., conducted a study of equations and experimental research of two-phase flow frictional pressure drop [12]. They revised 29 equations and obtained 3,480 experimental data from the literature. They stated that for flow in smooth pipes, the most commonly used explicit equation of single-phase friction factor equation is the Blasius equation [13, 14], which is a much more accurate explicit equation for flows in a rough pipe.

Meanwhile, Winning and Coole made the comparison between twelve explicit friction factor equations [15]. They found that the development of these equations is a function of the accuracy and computational efficiency. They stated that the selection or choice of the best or most proper equation is based on the predicted flow regime, relative pipe roughness, accuracy required, amount of calculations, and finally to take into consideration the uncertainties of the selected parameters.

Gosselin, *et al*., completed a review on the application of Genetic Algorithms (GAs) in the field of heat transfer and showed how the last decade witnessed an intense increment of their applications in solving problems related to optimization [16]. The fast progress made in computational technology is the other factor, which helped to make the use of computationally intensive tools easier for optimization and predicting the pressure drop.

Recently, Matheus, *et al*., combined genetic algorithms and artificial neural network with the aim to get a more universal equation. They stated that serious improvements can be accomplished in accuracy and validity of the equations by applying advanced optimization methods [17].

The objective of this study is to carry out a systematic multi-objective optimization with genetic algorithm (GA) to discover and examine the effects of applying data from different sources to calculate the Darcy friction factor. This in turn is used in the prediction of two-phase flow frictional pressure drop for turbulent flow regime in smooth and rough pipes in order to establish the differences. The first data source is from a paper reporting on experimental data collected specifically for a small channel. The second source is NIST, an established webbook of data based on macro channels while the last source is that has been recently provided by a partner university.

1.1 Frictional Pressure Drop

Ordinarily, the pressure loss due to friction when the fluid flows inside a pipe can be calculated by applying the Darcy-Weisbach equation [18]:

$$\Delta P = f_D * \frac{L}{D} * \frac{\rho \vartheta^2}{2} \tag{1}$$

where, f_D is the Darcy friction factor, L is the length of the pipe, D is the inner diameter of the pipe, ϑ and ρ is the velocity and the density of the fluid respectively.

The Darcy friction factor f_D or f_{2ph} is not a constant and depends on the parameters of the pipe and the velocity of the fluid flow. It can be computed for specific conditions by using various empirical or theoretical relations, or chart such as the Moody chart [19]. Therefore, the Darcy friction factor is sometimes called the Moody friction factor.

1.2 Friction Factor Equations

The friction factor represents the shear stress (or shear force per unit area) when the fluid flow exerts on the wall of the pipe. In a smooth pipe flow, the effect of roughness fully fades away in the viscous sub layer. Thus, the friction factor f_D is a function of Re and free from the effects of roughness (ε) on the flow. The Blasius equation is mostly used in calculation for the friction factor of turbulent flow in smooth pipes [20, 21]:

$$f_D = \frac{0.3164}{\sqrt[4]{Re}} \tag{2}$$

In a rough pipe flow, the thickness of the viscous sub layer is very small in comparison to the roughness height. Thus, the flow is affected by the roughness of the pipe wall and the friction factor is a function only of the roughness and is free from the effect of Reynolds number. Some of these equations give results that are very close to the result that the Colebrook-White equation gives. Fang, *et al*., had developed an explicit equation valid for the range $3 \times 10^3 < Re < 4 \times 10^8$, and ε between 0 and 0.05 [13]:

$$f_D = 0.3041 * \left[log\left(0.234\left(\frac{\varepsilon}{D}\right)^{1.1007} - \frac{60.525}{Re^{1.1105}} + \frac{56.291}{Re^{1.0712}}\right)\right]^{-2} \quad (3)$$

2.0 METHODOLOGY

The two-phase flow frictional pressure drop for a certain value of the mass flux, G, can be calculated by using the Darcy-Weisbach equation as follows:

$$(\Delta P_{2ph})_{frict} = f_{D,2ph} \cdot \frac{L}{D} \cdot \frac{G_{2ph}^2}{2\rho_{2ph}} \quad (4)$$

Ordinarily the average two-phase density ρ_{2ph} is calculated by the equation:

$$\rho_{2ph} = \left(\frac{x}{\rho_g} + \frac{1-x}{\rho_l}\right)^{-1} \quad (5)$$

where x is the vapour quality and subscript g and l refer to the vapour and liquid phase, respectively.

The friction factor is assumed to be constant along the test section with commendation of use of equation (2) for turbulent flow in smooth pipes. While for a turbulent flow in rough pipes, equation (3) is used, because it has maximum relative error of ± 0.50% with all existing equations [13].

The data of the refrigerant from different sources that are used in this study are listed in Table 1.

Table 1 Saturation pressure and physical properties of the refrigerant R-22 at saturation temperature at 10 °C

Data	P_{sat}	ρ_l	ρ_g	μ_l	μ_g	σ
[23]	0.68	1247.0	28.8	195.7	11.96	10.2
[24]	0.68	1246.7	28.8	193.7	11.8	10.2
[25]	0.68	1246.6	28.8	193.6	11.8	10.2

Knowing the Reynolds number, the flow regimes can be classified as laminar or turbulent. It is defined for different conditions of a fluid flow including the fluid properties and geometric characteristics. The Reynolds number is expressed as:

$$Re_{2ph} = \frac{G_{2ph} \cdot D}{\mu_{2ph}} \quad (6)$$

For a homogeneous two-phase flow, the average viscosity μ_{2ph} by McAdams *et al*. is commonly used in calculating the Reynolds number because it well predicts the experimental friction pressure drop according to Xu, *et al*., [12, 22]:

$$\mu_{2ph} = \left(\frac{x}{\mu_g} + \frac{1-x}{\mu_l}\right)^{-1} \quad (7)$$

where μ_l and μ_g are the dynamic viscosities of the liquid and gas phase, respectively.

The range of the mass flux G_{2ph} is chosen to be from 200 to 600 in order to be applicable to the experiments. Also the values of vapor quality x are chosen to be in the range of 0.0001 to 0.5. The number 0.0001 is chosen because GA tends to look for the lowest value to consider as an optimal solution.

According to Equation (4) a minimum two-phase flow frictional pressure drop can be achieved when the friction factor and mass flux are reduced as much as possible. For a minimum friction factor, the Reynolds number plays a crucial role, where the friction factor changes inversely with the Reynolds number. As seen from Equation (6), the mass flux is required to increase as much as required. This conflict makes the analyses more complex since the mass flux is affected by the fluid properties which are a function of the vapor quality. The effect of the mass flux on the pressure drop is demonstrated in Figure 1.

Figure 1 (a – d) demonstrates the intense effect of the mass flux on the pressure drop. An increase in the mass flux leads to an increase in flow velocity, which results in an increase in friction and acceleration pressure drops. Cho and Kim [26], Park and Hrnjak [27], and Oh, *et al*., [28] display analogous behavior of the pressure drop with the mass flux change.

Figure 2 (a – d) shows that an increase in vapor quality results in an increase of the pressure drop. Where an increase in heat flux leads to a high vaporization, and as a result increases the vapor quality and flow velocity. The results by Zhao, *et al*., [29] display analogous behavior of the pressure drop with vapor quality change.

Also Figures 1 and 2 show the effects of pipe diameter on pressure drop. The pressure drop in a smaller diameter channel is higher. Due to the wall shear stress being higher, this results in a higher friction factor and flow velocity. This leads to higher friction and acceleration pressure drops.

In general, the friction factor in turbulent flow regime depends on the Reynolds number as well as the roughness of the pipe wall and specifically on the relative roughness (ε/D). Figure 3 (a) and (b) demonstrates the effects of the relative roughness of the pipe on Darcy friction factor and two-phase friction factor. As expected the friction factor increases with the increasing of the relative roughness and correspondingly the pressure drop because of the active change and the influence of the two-phase with the inside wall of the pipe and with each other.

2.1 Multi-Objective Optimization (MOGA)

Optimization in a general case consists of finding the "best available" values of some objective functions at a given domain with respect to some criteria (or a set of constraints). Genetic Algorithms (GAs) are search algorithms based on the techniques of natural selecti -

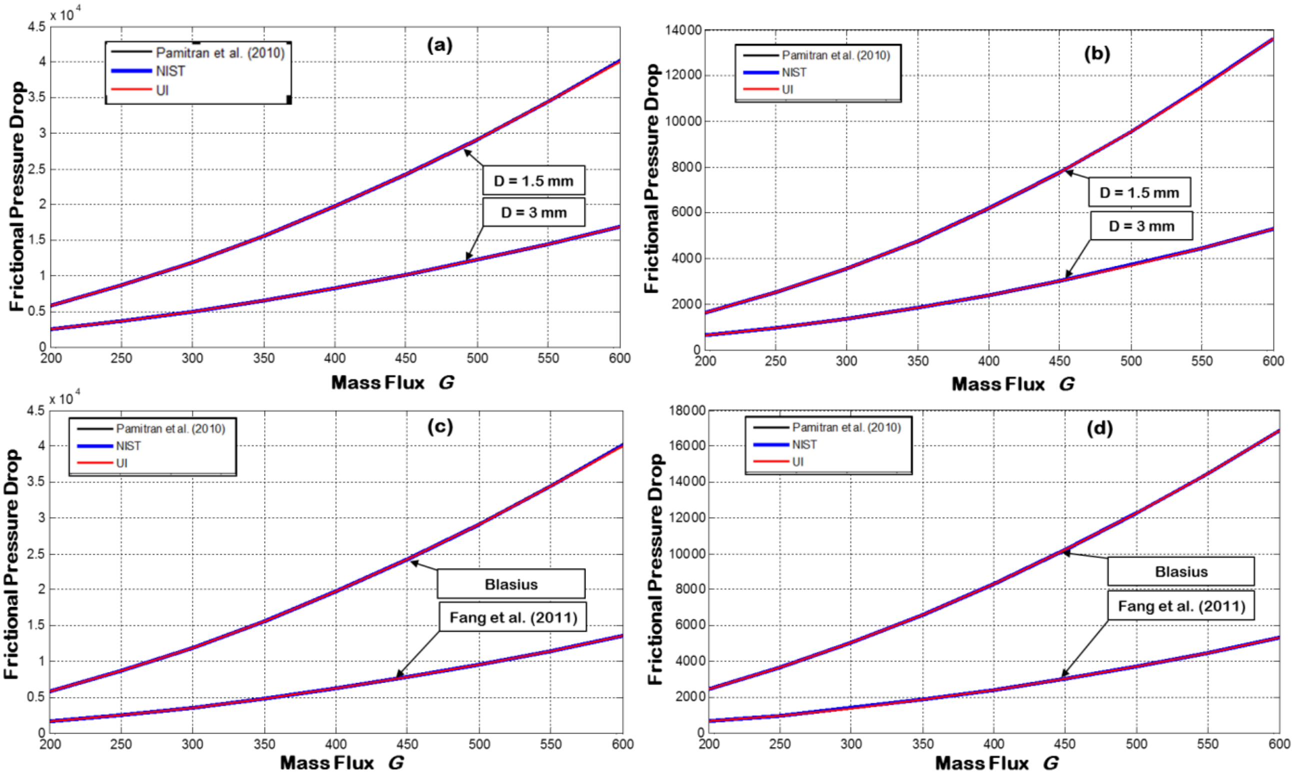

Figure 1 The effect of mass flux on two-phase flow frictional pressure drop of the refrigerant R-22: (a) Blasius equation, D=1.5 & 3 mm, (b) Fang *et al.* [13] equation, D=1.5 & 3 mm, (c) Blasius equation and Fang *et al*. [13] equation, D=1.5 mm, (d) Blasius equation and Fang *et al*. [13] equation, D=3 mm

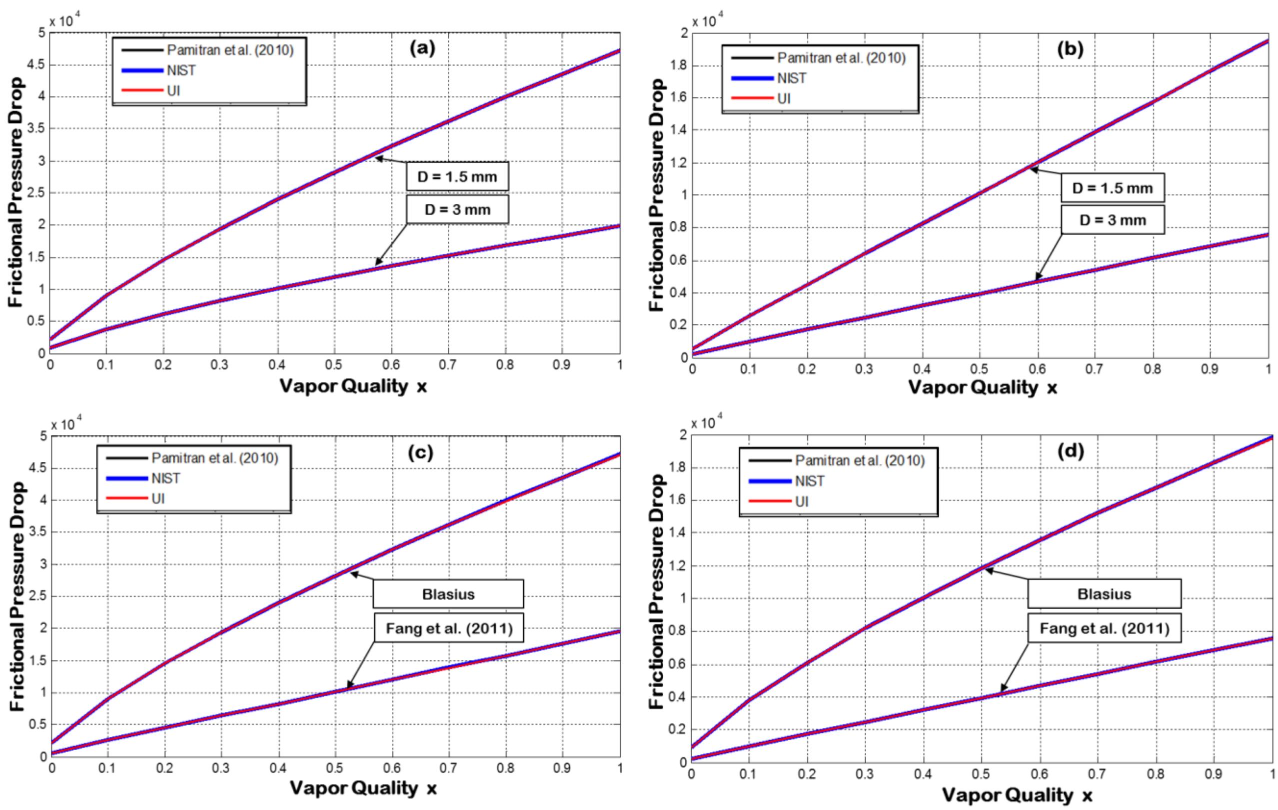

Figure 2 The effect of vapor equality on two-phase flow frictional pressure drop of the refrigerant R-22: (a) Blasius equation, D=1.5 & 3 mm, (b) Fang *et al*. [13] equation, D=1.5 & 3 mm, (c) Blasius equation and Fang *et al*. [13] equation, D=1.5 mm, (d) Blasius equation and Fang *et al*. [13] equation, D=3 mm

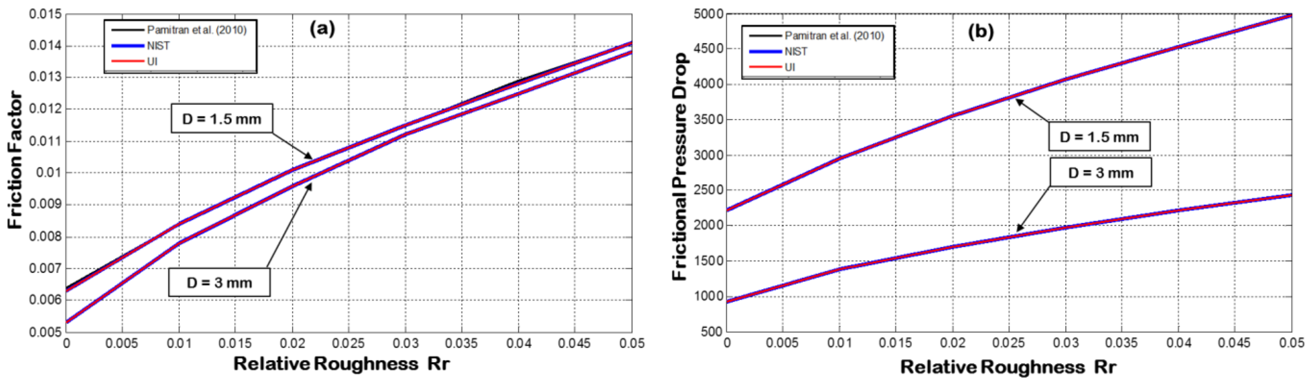

Figure 3 The effect of relative roughness on the: (a) Darcy friction factor and (b) two-phase flow frictional pressure drop of the refrigerant R-22 by using Fang *et al*. [13] equation inside pipe diameter of D = 1.5 & 3 mm

on which is a continuous process in a biological evolution like reproduction, mutation, and recombination [30, 31].

Multi-objective modes are the best and concrete models for optimizing complex engineering issues, especially when there is a conflict between the required goals. A sensible solution to a multi-objective issue is to examine a set of solutions such that each of them meets the expectations or satisfies the objectives at an agreeable scale with absence of control of any other solution. This set of solution is called Pareto optimal set [32]. The process of the GA optimization is shown in Figure 4.

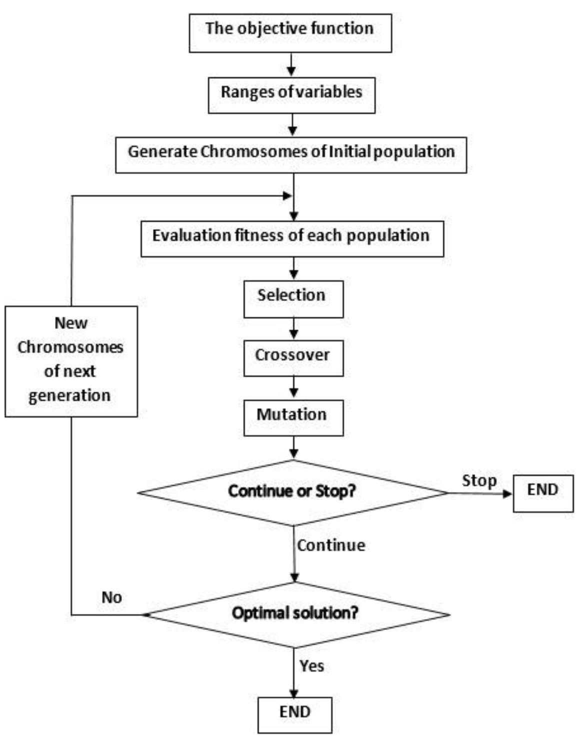

Figure 4 The GA flowchart

The multi-objective Genetic Algorithm (MOGA) optimization needs a minimum of two objective functions for optimization. The first objective function (f_1) is considered to be the two-phase flow frictional pressure drop, Equation (4). Meanwhile the second objective function (f_2) considered is the Darcy friction factor, Equations (2) and (3). Thus, Equation (4) is divided into two parts of (η) and (f_D) as follows:

$$(\Delta P_{2ph})_{frict} = \eta \cdot f_D \quad \text{or} \quad f_1 = \eta \cdot f_2 \tag{8}$$

where,

$$\eta = \frac{L.D}{2\rho_{2ph}} G_{2ph}^2 \tag{9}$$

MOGA is performed using the optimization toolbox in MATLAB 2014a [33], with the optimization of the fitness functions completed simultaneously with their variables. The parameters setup in the Toolbox optimization is shown in Table 2.

Table 2 Toolbox parameters setup in MATLAB 2014a

Number of Variables	2
Population type	Double vector
Population size	Default: 20×2(Number of variables)=40
Selection	Selection function: Tournament
Initial population	Default: by creation function
Reproduction	Crossover function: Default: 0.8
Mutation	Mutation function: Constraint dependent
Plot function	Pareto front

The population size is chosen to be 40, which means that for every generation, GA will select 40 of the best solution. Therefore, the population size should be logical to keep away from more computational time. The initial population is formed by default by creation function. The crossover fraction of 0.8 means that 80% of the solutions will subject to the crossover process for reproduction.

The points of solutions are the points where both f_1 and f_2 are the non-inferior or non-dominated points by variables G_{2ph} and x.

3.0 RESULTS AND DISCUSSION

With the aim to evaluate the equations of Blasius and Fang *et al*. [13] from different data source; from Pamitran *et al*. [23], NIST [24], and UI data [25], the range of the friction factor (extracted for the purpose of discussion) obtained is from 2.92 to 3.24 in a pipe of 1.5 mm inner diameter and from 2.5 to 2.8 in a pipe of inner diameter of 3 mm. This is because most of the Pareto solutions are found here. These outcomes are from using the Blasius equation as shown in Figure 5. While the range of the friction factor for the most Pareto optimal solutions for Fang *et al*. [13] in a pipe of 1.5 inner diameter is from 0.0094 to 0.01 and from 0.0073 to 0.0075 in a pipe of inner diameter 3 mm with the Pareto frontier shown in Figure 6.

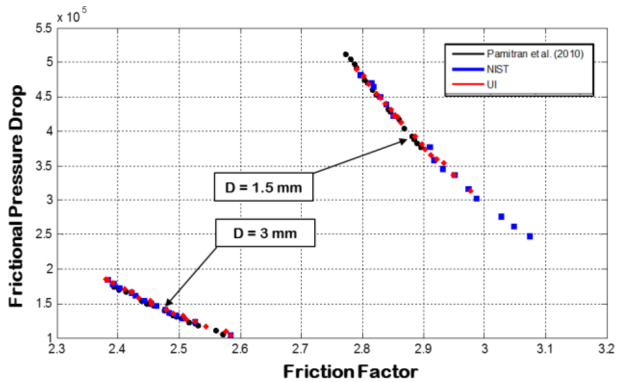

Figure 5 Pareto frontier from different data of Blasius equation for the refrigerant R-22 inside pipe diameter of D = 1.5 & 3 mm

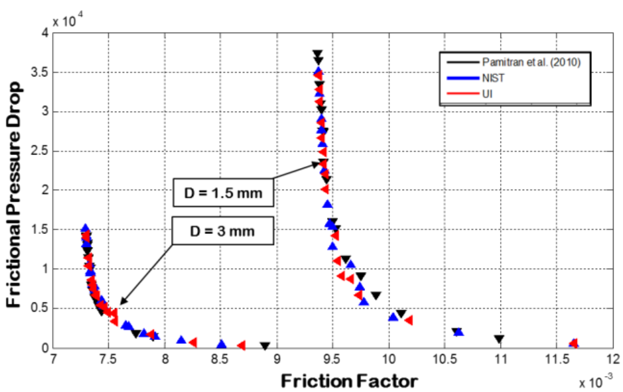

Figure 6 Pareto frontier from different data of Fang *et al*. (2011) equation for the refrigerant R-22 inside pipe diameter of D = 1.5 & 3 mm

Table 3 and 4 offer the identified optimized results of f_D and $(\Delta P_{2ph})_{frict}$ with their own values of vapor quality and mass flux from Blasius and Fang *et al*. [13] in 1.5 and 3 mm inner diameter respectively.

Table 3 Optimized solutions of f_D and $(\Delta P_{2ph})_{frict}$ from Blasius [21]and Fang *et al*. [13] in D=1.5mm

Equation	Data	x	G	f_D	$(\Delta P_{2ph})_{frict}$
Blasius [21]	[23]	0.0012	474.59	2.92	370456.7
		0.0005	310.14	3.24	170559.6
	[24]	0.0001	471.46	2.92	349287.8
		0.0007	319.06	3.23	181116
	[25]	0.0002	474.29	2.92	354424.9
		0.0001	311.47	3.24	169397.2
Fang *et al.* [13]	[23]	0.4932	499.04	0.0094	27352.66
		0.0976	401.38	0.01	4444.045
	[24]	0.4469	528.93	0.0094	27982.44
		0.0481	551.99	0.01	4985.25
	[25]	0.4926	495.86	0.0094	26949.67
		0.0844	419.21	0.01	4327.96

Table 4 Optimized solutions of f_D and $(\Delta P_{2ph})_{frict}$ from Blasius [21] and Fang *et al*. [13] in D=3 mm

Equation	Data	x	G	f_D	$(\Delta P_{2ph})_{fric}$
Blasius [21]	[23]	0.0003	435.6	2.50	128642
		0.0002	282.1	2.79	60013.2
	[24]	0.0001	411	2.54	115510
		0.0002	267.6	2.83	54907.5
	[25]	0.0005	434.8	2.51	129795
		0.0006	282.6	2.80	61527.7
Fang *et al.* [13]	[23]	0.499	571.5	0.0073	14110.6
		0.435	253.7	0.0075	2506.7
	[24]	0.499	553.2	0.0073	13216.8
		0.428	257.3	0.0075	2540.1
	[25]	0.493	560.9	0.0073	13423.2
		0.262	406.6	0.0075	4005.2

Table 5 and 6 show the relative differences between the results when different data are used in obtaining f_D and correspondingly $(\Delta P_{2ph})_{frict}$. Table 5 shows that the minimum difference using the Blasius equation for a 1.5 mm inner diameter tube at specific friction factor of 2.92 is about 0.0147 when NIST and UI data are used for calculating friction factor, and 0.0068 at friction factor of 3.24 between Pamitran *et al*. [23] and UI data [25]. While the minimum difference for the same inner diameter using the Fang *et al*. [13] equation is about 0.0147 and 0.0261 when Pamitran *et al*. [23] and UI data [25] at a particular friction factor of 0.0094 and 0.01 respectively.

Table 5 The relative differences in $(\Delta P_{2ph})_{frict}$ due to different data inside pipe D = 1.5 mm

Equation	$f_D = 2.92$		
	[23]	[24]	difference
Blasius [21]	370456.7	349287.8	0.0571
	[23]	[25]	difference
	370456.7	354424.9	0.0432
	[24]	[25]	difference
	349287.8	354424.9	0.0147
	$f_D = 3.24$		
	[23]	[24]	difference
	170559.6	181116	0.0619
	[23]	[25]	difference
	170559.6	169397.2	0.0068
	[24]	[25]	difference
	181116	169397.2	0.0647
Fang *et al.* [13]	$f_D = 0.0094$		
	[23]	[24]	difference
	27352.65	27982.44	0.0230
	[23]	[25]	difference
	27352.65	26949.67	0.0147
	[24]	[25]	difference
	27982.44	26949.67	0.03690
	$f_D = 0.01$		
	[23]	[24]	difference
	4444.04	4985.25	0.1218
	[23]	[25]	difference
	4444.04	4327.96	0.0261
	[24]	[25]	difference
	4985.25	4327.96	0.1318

Table 6 shows that the minimum differences from Blasius equation in 3 mm inner diameter are about 0.0089 and 0.0252 when Pamitran *et al*. [23] and UI data [25], at certain friction factor of 2.50 and 2.80 respectively. While from Fang *et al*. [13] the minimum differences in the same inner diameter are about 0.0156 and 0.0133 when Pamitran *et al*. [23] and UI data [25] at friction factor of 0.0073 and Pamitran *et al*. [23] and NIST data [24] at friction factor of 0.0073 and 0.0075 respectively.

These differences possibly happen because of the selection of the different values of mass flux and vapor quality. The obtained results demonstrate that the mass fluxes for Blasius equation results are ranging from 310.14 to 474.59 kg/m^{2}s and vapor quality from 0.0001 to 0.001218. While for Fang *et al*. [13], the mass fluxes are ranging from 401.38 to 551.99 kg/m^{2}s and vapor quality from 0.0481 to 0.4932. This is because the maximum limit of mass flux is setting to be 600 kg/m^{2}s in optimization setup and vapor quality range is from 0.0001 to 0.5. So here the focus must be done on mass flux because it is the unique variable which can be controlled while vapor quality cannot.

Table 6 The relative differences in $(\Delta P_{2ph})_{frict}$ due to different data used inside pipe with D = 3 mm

Equation	$f_D = 2.50$		
	[23]	[24]	the difference
Blasius [21]	128642	115510.1	0.1021
	[23]	[25]	the difference
	128642	129794.9	0.0089
	[24]	[25]	the difference
	115510.1	129794.9	0.1236
	$f_D = 2.8$		
	[23]	[24]	the difference
	60013.18	54907.44	0.0851
	[23]	[25]	the difference
	60013.18	61527.74	0.0252
	[24]	[25]	the difference
	54907.44	61527.74	0.1205
Fang *et al.* [13]	$f_D = 0.0073$		
	[23]	[24]	the difference
	14110.59	13216.78	0.0633
	[23]	[25]	the difference
	14110.59	13423.2	0.0487
	[24]	[25]	the difference
	13216.78	13423.2	0.0156
	$f_D = 0.0075$		
	[23]	[24]	the difference
	2506.66	2540.08	0.0133
	[23]	[25]	the difference
	2506.66	4005.22	0.5978
	[24]	[25]	the difference
	2540.08	4005.22	0.5768

Figure 7 (a) and (b) and Tables 7 and 8 offer the comparison that the optimized solutions of the Blasius [21] and Fang *et al*. [13] equations from the use of different data source is characterized by a large variation and differences. The reason behind this is that the Blasius equation does not take into consideration the effect of the roughness because it does not contain term for roughness while Fang *et al*. [13] equation does.

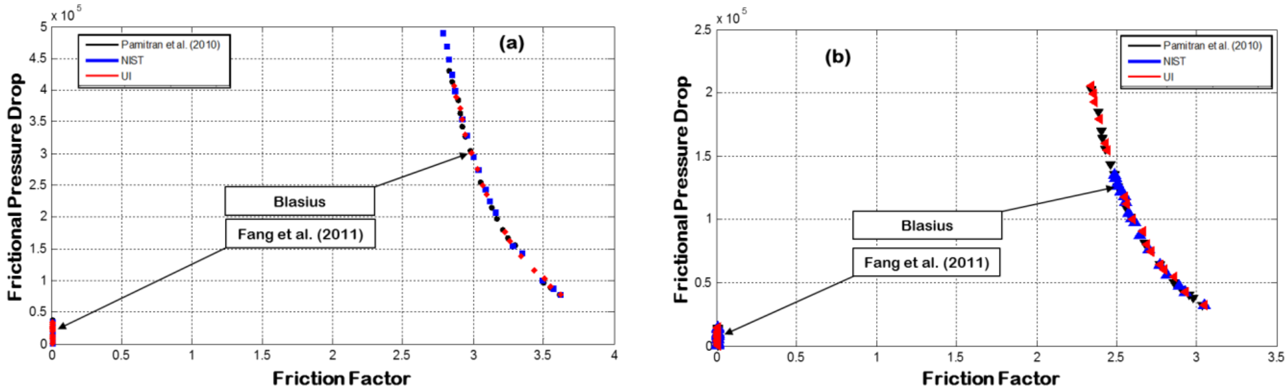

Figure 7 Pareto frontier from different data of Blasius and Fang *et al*. (2011) equation: (a) D = 1.5 mm, (b) D = 3 mm.

Table 7 Relative differences between the results of $(\Delta P_{2ph})_{frict}$ from Blasius [21] and Fang *et al*. [13] due to the use of different data inside pipe diameter of D = 1.5 mm

D	$\max(\Delta P_{2ph})_{frict}$			
	Data	**Blasius**	**Fang**	**rel. difference**
1.5 mm	[23]	370456.7	27352.7	0.9261
	[24]	349287.8	27982.4	0.9198
	[25]	354424.9	26949.7	0.9239
	$\min(\Delta P_{2ph})_{frict}$			
	[13]	170559.6	4444.0	0.9739
	[24]	181116	4985.3	0.9724
	[25]	169397.2	4328	0.9744

Table 8 Relative differences between the results of $(\Delta P_{2ph})_{frict}$ from Blasius [21] and Fang *et al*. [13] due to the use of different data inside pipe diameter of D = 3 mm

D	$\max(\Delta P_{2ph})_{frict}$			
	Data	**Blasius**	**Fang**	**rel. difference**
3 mm	[23]	128642	14110.6	0.8903
	[24]	115510	13216.8	0.8855
	[25]	129795	13423.2	0.8965
	$\min(\Delta P_{2ph})_{frict}$			
	[23]	60013.2	2506.7	0.9582
	[24]	54907.4	2540.1	0.9537
	[25]	61527.7	4005.2	0.9349

All figures and tables displayed and confirm one fact, which is the value of pressure drop is highest in areas where the friction factor is low. Also they confirm that the values of friction factor are approximately close to each other with a small difference while for $(\Delta P_{2ph})_{frict}$ the values of up to double and sometimes more.

Finally, we must not lose sight of the clear and obvious visible fact that the values of the pressure drop in the small diameters are always higher than in the bigger, although the actual need for the use of small appliances increases from day to day with increasing sophistication. This prompting researchers to use and application of modern methods to get to faster and more accurate results, including the Genetic Algorithms.

4.0 CONCLUSION

The study, is done by applying genetic algorithm as an optimization tool using different data from Pamitran *et al*. [23], NIST [24], and UI experimental data [25] to calculate the friction factor. Two equations have been used; Blasius and Fang *et al*. [13] equation. It has been proven that there are differences in results of the friction factor which is the main component of the frictional pressure drop calculation. The comparisons between results showed that the lowest differences are between the results from Pamitran *et al*. [23] and NIST data [24] in 1.5 and 3mm pipe inner diameter about 0.68% and 0.89% for the Blasius equation respectively. While the lowest differences are between the results from Pamitran *et al*. [23] and UI data [25] in 1.5 mm pipe inner diameter, about 1.47% and 1.33% between the results from Pamitran *et al*. [23] and NIST data [24] in 3 mm pipe inner diameter from Fang *et al*. [13] equation.

These differences are great and has a decisive influence on the work associated with the design of the desired device. It is imperative that specific accurate data is used to calculate the friction factor and predict the pressure drop in order to obtain the required accuracy.

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