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Article

Fluid dynamics analysis for a production line

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Abstract: Magnetic filters are used on companies for mass flux and volume flux values that help to cover day-to-day production. This work begins by describing the problem of magnetic filter fractures as of industrial interest. A brief description of how magnetic filters must work on applications according to requirements on the process line. On the next section, it is possible to find the explanation of structural fractures and mistakes on the design or data sheet, which are usually not considered in guaranteed policy. Are mentioned more than one math modeling, taking the simplest to show the effective value of maximum pressure tolerated on magnetic filters differs from estimated for controlled conditions. Solutions shown in the article are a first approach to a future general model theory that could explain how applied science works in a factory where there is no time to stop production. This work relates the math model and some values to application, meaning both the project hypothesis modeling and factories requirements for their equipment. Results depict volume, velocity, density, and pipeline relation to the pressure increase over the values on the data sheet from quality department tests. Conclusions describe the connection of the math model analysis with real situations on the application or possible structural damage. And its relationship with the proper function of magnetic filters for the purpose of lifespan analysis on future works. This work is a proof that in a few weeks, companies can have a solution for their problems, letting them buy some time to avoid any future issues.

Keywords: magnetic filters; turbulence; mass flux; fluid dynamics; industry; production line; fluid pressure

1. Introduction

On every production line or quality assurance that requires constant flow on any section, there is a fluid (liquid, gas, or a mix of both) that could have ferromagnetic particles mixed with the product. Those particles could be harmful for the final customer for food production or processing. These metal particles can damage equipment and measuring instruments due to friction, eddy current generation, or a non-controlled pressure increment. For the cleaning of such materials, industries get magnetic filters installed as part of pipelines [1–4]. Filters use rare earth magnets on the inside of rods. Guarantee policy usually includes tables about pressure limits, temperature, and useful lifetime [5]. This data sometimes comes from experiments or factory tests asked for quality processes. Not all industries consider them for their process or quality control, due to the environmental conditions as pressure from an air injector (or water injector), as directors want something for every scenario possible.

Real environmental conditions [1,3,4,6,7] of magnetic filter usage seem not considered in experiments or theoretical studies. A lack of quality standards. Higher density, greater viscosity, noise (more than one kind) [8], and overheating are conditions that make real systems work far beyond predictions [6,9–11]. Every time a fluid passes through the magnetic field, some physical effects occur; there is no control over the functioning [2,6]. Efficiency drops because of non-considered effects on the fluid [12] or magnetic dynamics.

Analyzing structure [1–4], thermal properties [6,7], side-effects [11], and phenomena [6,7,13] on manufacturing or cleansing processes as a research project is not possible for most factories. Numerical methods are limited to the precision and accuracy of math equations and are not considered for application. The so-called toy models are based on oversimplified, quick analysis of some physical phenomena. Even that kind of research can take months to years or decades to get a solution. That kind of investment (time and resources) is not an element for managers' protocols.

A brief math modeling should be studied as the process continues. Most dynamical systems include equations for virtual work and virtual energy resolutions [6]. Even with access to the process line, some conditions are not part of the analysis, like external environment conditions (air flux on the company, cleaning, shocks, external vibration, not controlled humidity, and heat sources). Rust, structural fracture, and vibration are elements that shorten the lifespan of equipment. Most of the predictive systems on quality assurance are modeled for a perfect environment that would not have irregularities, humidity, or changes in the working cycle.

Such filters are manufactured on several parts, having some magnetic rods on the inside (the amount depends on the factory and model). There are two kinds of alignment for the rods: 1) a circle near the metallic wall, and 2) a circle with a central rod. In both cases, the fluid collides against rods, generating a rotational system on two axes (up-down, side-to-side) for the fluids [13]. Other considerations could be part of the analysis for an approach: if there is some deposition of material or ferromagnetic particles on the lowest part of the vase.

2. Analysis of equipment operation

A magnetic filter has a constant incoming fluid [1–4] for different kinds of materials according to each factory. Ferromagnetic particles get attracted by the magnetic field of rods: viscous fluid gets inside, passes through magnets, and gets cleaned, retaining ferromagnetic contaminants, then it leaves the filter. There are several values of pressure on the filter [5]: max tolerated by the structure, expected pressure, and effective pressure. Turbulence, fluid rotational, torque, and force excess occur once the fluid passes [12]. On the process line, we find some complications: changes in pipeline diameter, acceleration of fluid for changes in direction, and open-closed valves.

Pressure can be defined as the effect of average collisions of molecules of a body (fluid or solid) against the container or internal collisions [6,8]. On real systems, turbulence means a constant increase of direction and acceleration, then pressure increases [5]. Molecules colliding with each other means an increase in temperature; this is another average measurement of the kinetic energy of molecules and their dynamics. Changing the heath can generate a volumetric expansion, with a pressure increase as a consequence.

All previous dynamics are related to fluid density, mass flux, and diameter of pipeline. The technical data sheet comes with a table of pressure values expected from an extrapolation due to an experimental test on a controlled environmental system. Such tables are uncertain, as every factory has its own suppliers. Instead of calculating a table for each company, a complete math model can be developed.

Avoiding problems with measuring, the geometric structure is not analyzed with values. Instead, it can be described using proportions. From a list of products, the most bought have a four-inch radius. According to space and volume, the main characteristic is diameter variation. Using the percentage change. As greater the reduction in diameter, greater the pressure increase. As greater the change in pipeline, greater the turbulence factor.

There are two ways of analyzing. On one hand, net effective pressure is a characteristic that tells us how pressure by fluid collision has its max value inside the filter. On the other hand, changes in pressure can give information about the surplus for elements like the magnetic rods.

On factories, there is not enough time to measure the flow on pipelines, put pressure on every step, or stop processing [5]. Just some of the values can be measured, like pipeline diameter, initial flow velocity, and initial pressure.

3. Mathematical analysis

Some elements are not constant under the considerations of mechanical vibrations and torque direction. In this case, for fluid analysis [7,12], main characteristics are volumetric flux ($Q = Av\cos\theta = Av = \sqrt{H/sL}$) and mass flux ($\dot{m} = \rho VS$) for the dynamics. For quality department tests, the fluid is stablished under some controlled conditions with no vibrations, no turbulence, and underwater pressure (water injection on a short pipeline) [5]. Mechanical vibrations generate some noise on the fluid and a nonlinear turbulence as well as nonlinear rotational for the pressure [2,6,7,9,11–13]. As an approximation for the solution, are necessary both a toy model (no pressure gradient, no turbulence) and another with pressure as an experimental approach on the consideration of real data. The real phenomenon with no linearity was studied together.

For this brand, maximum pressure tolerance is estimated as 200 PSI (water pressure test for a short pipeline). Due to ISO and other normatives, filters can vary in their effectiveness by 10% [5]. Tolerance for the effective pressure on the processing, so the factories need to consider a greater value for the requirements of the clients. Max pressure is only information for the brand, not on the data sheet. Top values for every industry could not be the same.

Navier-Stokes [7] and Bernoulli equations for fluid mechanics describe a system with spatial and temporal dependence, with some factors like gravity and density, that most of the time are unknown. The first one can have a temporal variation, giving a real-time analysis. The second one represents how pressure, gravity, and geometry change force or its increase on the pipeline. The effective value for force, pressure, and flux comes from the nonlinear math analysis of fluid dynamics inside the filter once it collides with the magnetic rods.

Another not-known value is the original height (from the ground) for the pipeline, neither the final one if there is a variation. Is it possible to watch an industry's process and measure those heights (as many other parameters)? Every factory has different infrastructure. Consider this height as constant on a long enough pipeline to avoid variation in calculus. The general view on the operation can be described as follows:

- Fluid travel through pipeline (no variations on structure) for an unknown extension.
- Fluid enters the filter. Turbulence and rotational dynamics are part of equations [13].
- After the cleaning, fluid flow out from filter with a different speed from the first step.

First and second are an issue for proper magnetic filter operation. Considering that once the fluid flow out, it keeps traveling through pipeline of a constant diameter. On the first equation, for Bernoulli on the non-compressible fluid transmission:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \tag{1}$$

Height must be constant for at least one meter, for the math model to represent the real phenomenon according to experimental data. First pressure is the one from the pipeline before the filter, and the second pressure corresponds to the value inside the pipeline. Pressure as force per area unit, is useful to describe it with flux and time as parameters:

$$P = \frac{F}{S} = \frac{mv}{(Q/v)t} = \frac{mv^2}{Qt} = \frac{mQ^2}{A^2 t} \tag{2}$$

Such equation implies that increasing the mass flux can rise pressure (as a real application). Substitution of this factor as first pressure on pipeline on the Bernoulli equation, gives an identity for the second pressure (inside filter). According to density definition, if the volume changes, the density does too. For both considerations, pressure inside the filter:

$$P_2 = \frac{3}{2}\frac{\rho Q^2}{A^2} - \frac{1}{2}\rho v_2^2 \tag{3}$$

Once the fluid enters the filter, it expands due to the change in radius from the pipeline to the vase. Sometimes it can be compressed for a reduction in pipeline diameter. It depends on the factory.

Rotational and divergence are responsible for accelerations on all axes [7]. Physics, math, and technical concepts are not used in some factories, for them, there is no such thing as pressure gradient or variation. Those values cannot be evaluated. Initial velocity is determined by the pumps on the system or by free fall. The second speed (on the inside) is a function of the original velocity ($v_2 = v_2(v_1)$) and other parameters. There is a voracity, read as the natural frequency (or frequencies) of the fluid during the process:

$$\omega = \nabla \times v \tag{4}$$

Factories do not work under the same rules, protocol, or processes. Not all of them use top pressure as guidance [5,7]. Some consider other measures from several dynamics: mass flux, total inner volume, volume per minute, density, and some others. Some of them are necessary for the understanding of the proper use of the filters. For steady flow with no gravity [12], frequency can be approximated on the solution of a simple version of the Navier-Stokes equation [7]:

$$\frac{D\omega}{Dt} = \omega \cdot \nabla u + \nu \nabla^2 \omega \tag{5}$$

Represents the vorticity on the system. Four-dimension system, with spatial represented as a radius and angle. Is it possible to demonstrate that there is a trigonometric solution for a well-behaved case with a complex exponential time factor? To make math simple for non-specialized personnel, consider the definition of the vorticity through the rotational equation:

$$\omega = \omega_0 \frac{r_0^2}{r^2} = \frac{v_1}{r_0} \frac{r_0^2}{r^2} = \frac{Q}{A} \frac{r_0}{r^2} \tag{6}$$

Mass flux, PSI, flow velocity, and pressure are mandates on industries to understand the process; they don't mind if there are proper terms on the physical/engineering systems [5,12]. Using vorticity and the Bernoulli equation, the pressure of the filter vase can be estimated with parameters controlled as pipeline radius, vase radius, mass flux, and fluid density (if not known, can be approximated for water values):

$$P_2 = \frac{\rho Q^2}{2A^2} \left(\frac{3r_2^2 - r_0^2}{r_2^2} \right) \tag{7}$$

Forces and velocities (linear and angular) are implicit parameters of all equations depicted. Forces according to energies is an analysis for future works to stablish relations with the engines. Fluid elasticity allows to maintain the form during flowing. Also does the surface tension that breaks momentously once it enters the vase, generating a force (or a vacuum) that pulls fluid inside. That's the first acceleration. The other forces come from rotational due to the change in direction and change in velocity due to volume expansion [13]. Stablishing another Navier-Stokes variation [7] related to solid materials dynamics and structural analysis, substituting Equation (4) onto Equation (5), considering bulk modulus of fluid:

$$\frac{VB}{\Delta t} \nabla \cdot \vec{u} = m\omega \nabla \cdot (\nabla \times \vec{u}) \Delta r \tag{8}$$

Partial differential equations, tensors, and stochastic equations are options for a solution on an approach to real applications [7]. The superposition principle requires a linear combination of solutions from different methods and conditions, even if they are nonlinear. The greater the number of solutions, the closer to reality. Tensorial equations are the middle point of complexity for solving, best for fluid dynamics. Considering pseudo-tensor using summation and dyadic for parameters: fluid volume and the mass flux using Equation (6). Solution as pressure that relates changes in group velocity (for perturbations), mass, and cross-sectional area proportion, making this an exchange of energy inside the pipeline. As well as proportion to bulk modulus and group velocity:

$$P \sim \frac{B r_2^2 V}{Q r_0} u_i = \frac{m}{A} \frac{\partial_i u_j \partial^2 \delta_{ij}}{u_i} \tag{9}$$

Even when Equation (9) still has derivatives, this is a tensor describing deformation of the fluid. Derivatives are not changing rate but still considered as an approach for application in a fast-working environment. Peak technology is not available in all factories, so there is no way to solve equations or evaluate functions constantly, neither using advanced programs. The best option for a real-time application is to use a simplified version, then evaluate the data.

Until now, the options for pressure function were: Equation (3) for the case of mass flux and velocity as main parameters; Equation (7) considering the change in velocity as a rate of pipeline diameter and filter size; and Equation (9) that analyzes pressure related to mechanical properties from the fluid conditions. Previous equations generate net pressure evaluation from mechanical and geometrical proportions as a system related to temperature, useful for applications:

$$(\Delta P)^2 = P_2^2 + P_3^2 = \left[\frac{\rho Q^2}{2A^2}\left(\frac{3r_2^2 - r_0^2}{r_2^2}\right)\right]^2 + \left[\frac{Br_2^2 V}{Qr_0}u_i\right]^2 \tag{10}$$

Group velocity is necessary to approach mass flux and volumetric flux. It is related to pipeline and fluid mechanical properties. Implicit parameters are out of reach of the article but still necessary for a better understanding: viscosity, elasticity, surface tension [7,10,12]. This velocity can be named effective flux:

$$u_i = \frac{Q}{AB}\frac{r_0}{r^2}\rho\partial_i u_j \partial^2 \delta_{ij} \tag{11}$$

Equation (10) is necessary for the close approach to application on industrial process lines. On future works, we must use a program to evaluate several parameters to stablish multiple tables for possible scenarios on the application. Thinking on the industries, the simple is to give them Equation (7) to evaluate easy-to-measure values and get some data for the quality process. Inquiring how close to optimal functionality are the magnetic filters.

4. Results and discussion

There is a nominal or expected pressure on magnetic filters [1–5]. Those are the values that a factory is expecting for a process line. Pressure can generate implosion of structure [11] if it is lower than optimal range. Above the maximum pressure value, it could cause structural fractures, leaks, or pipeline explosions. Calculating the effective pressure leads to understanding problems in the process. All the products studied have a tolerance for the maximum pressure supported. That can vary from 5% up to 15%. Depends on materials, operating conditions, manufacturing process, and environmental conditions.

That tolerance assures that fluid would exceed pressure on the filter without damage or explosion. If the production is not controlled, the pressure remains a problem, as it could exceed the maximum value. For factories that require the use of magnetic filters [1,3,4] the best option is to reduce mass flux, volume flux, or production per hour, meaning an incoming loss. The factories that produce the filters should build better equipment with greater maximum allowable pressure. Reporting a selected nominal pressure, stablishing two tolerances, one for the data sheet and the other (the highest one) for quality control.

The same for the lifespan and other characteristics. Due to any non-expected functioning conditions on the final customer installations.

Once the diameter changes at mass flowing from pipeline to filter, force, vorticity, and pressure increase can stay below the top pressure or under the tolerance rate. Could be greater than tolerance. Equations like Equation (7) calculate the excess of the pressure (PSI) on the filter due to the change of diameter and available space for the fluid.

Such a rate of variation seems negligible, but this is a percentage per cycle, not the entire process. The preferred use of the filters is to process the fluid and then stop using it some time for relaxing of the structure. After that, another cycle and go on. For the industry, the less time between cycles is the better. Process lines are designed for constant functioning, and even no shutdown is possible unless there is time for maintenance or repair.

Different mechanical properties for each fluid: density, viscosity, surface tension, elasticity, and heat capacity [7]. Applications should be a math development for every condition or a general model. Instead, a simplified version of the phenomenon can assure that tests on quality departments are not enough. Neither water nor air are common in the pipeline of industrial processes. If liquids are mixed with some solid particles or dust, the fluids have neither linear density nor pressure rating nor measuring.

Production of a week represents thousands of cycles of use per filter, then a greater than expected increase in pressure and heating for the cleaning. Thousands of cycles can mean near 1% of an increase. On that condition, the excess pressure on a constant use with no time for cooling would fracture the structure or reduce the magnetic intensity of rods.

For factories in Mexico, more production means more sales, more money (as a first thought). Maintenance is scheduled under data sheet recommendations and according to income. As mentioned before, the data sheet is calculated for ideal conditions. This kind of table depicted in the article should be on every factory that produces magnetic filters so they can offer their products according to customer needs.

Magnetic filter design and manufacturing can be improved through the study of a solution of tensorial mathematical model for general variables. Even considering volume increase at every time or compressions due to mass flux. There is an expansion generated by heat gradient, which is represented as percentual changes of some thermodynamic conditions (temperature, relative humidity, room atmospheric pressure) on quality departments.

Manufacturing implies the point between theory and application. Sometimes that theoretical modeling is only approximations, and simplified systems can be analyzed for the time allowed.

Tables 1 and **2** show how rates from pipeline to filter have a direct effect on pressure and volume change. As shown in equations, even if the diameter of the magnetic filter is greater than the pipeline, there should be a pressure change. Volume change (expansion and compression) on the pipe induces a pressure change, in most cases an increase. Even when there is more space (no significant pressure increasing), a heating process happens due to collisions on the new directions, i.e., the velocity gradient or rotational field [13–17].

International standards require that information should be reported to the public as values from the International Unit System (SI), but factories are still using the imperial system. Tolerances must be written as percentages due to the confusion from units on the imperial system to SI. These tables show information as PSI (pounds per square inch) and volume (meters) being the most mentioned on the data sheet, product catalog, and marketing.

Table 1. Values for excess of pressure per cycle on a process line for the smallest diameter.

Filter dimensions (inner radius) (1.5–2 IN/51 MM)						
Relative pipeline diameter						
%*	**Liquid fluid**		**Fibrous or doughy**		**Viscous or heavy**	
	Pressure (PSI)	**Volume (m^3)**	**Pressure (PSI)**	**Volume (m^3)**	**Pressure (PSI)**	**Volume (m^3)**
55	0.000943	0.001013	0.000646	0.009180	0.000267	0.003793
60	0.000793	0.001206	0.000543	0.007587	0.000224	0.003135
65	0.000675	0.001415	0.000463	0.006375	0.000191	0.002634
70	0.000582	0.001642	0.000399	0.005432	0.000165	0.002244
75	0.000507	0.001884	0.000347	0.004684	0.000144	0.001935
80	0.000446	0.002144	0.000305	0.004080	0.000126	0.001686
85	0.000395	0.002420	0.000271	0.003586	0.000111	0.001482
90	0.000352	0.002714	0.000241	0.003176	9.9721×10^{-5}	0.001312
95	0.000316	0.003023	0.000217	0.002833	8.95×10^{-5}	0.001171
100	0.000285	0.003350	0.000195	0.002543	8.0774×10^{-5}	0.001051

*The percentual variation from the pipeline before the magnetic filter to the opening.

Table 2. Values for excess of pressure per cycle on a process line for other model, considering simple fluids.

Filter dimensions (inner radius) (3.5–4 IN/102 MM)						
Relative pipeline diameter						
%**	**Liquid fluid**		**Fibrous or doughy**		**Viscous or heavy**	
	Pressure (PSI)	**Volume (m^3)**	**Pressure (PSI)**	**Volume (m^3)**	**Pressure (PSI)**	**Volume (m^3)**
55	0.018543	0.019920	0.012877	0.011432	0.009672	0.010390
60	0.015581	0.023706	0.010820	0.013833	0.008127	0.012365
65	0.013276	0.027822	0.009220	0.016463	0.006925	0.014512
70	0.011448	0.032267	0.007950	0.019321	0.005971	0.016831
75	0.009972	0.037041	0.006925	0.022408	0.005201	0.019321
80	0.008765	0.042145	0.006086	0.025723	0.004572	0.021983
85	0.007764	0.047577	0.005391	0.029267	0.00405	0.024816
90	0.006925	0.053339	0.004809	0.033040	0.003612	0.027822
95	0.006215	0.059431	0.004316	0.037041	0.003242	0.030999
100	0.005610	0.065851	0.003895	0.041271	0.002926	0.034348

**The percentual variation from the pipeline before the magnetic filter to the opening.

0.01039 m^3 equals 10,390 cm^3, which is a high value meaning a compression on the system. That compression raises the temperature and pressure. **Tables 1** and **2** show the increase of the volume once its diameter changes from the pipeline to the inside of the magnetic filter. Math correlation seems appropriate; as greater the inner radius of the filter, greater the volume expansion allowed. It is possible to analyze that as the inner radius of the filter increases, it can tolerate more compression on the volume of fluid. For a 55% diameter reduction, from the 1.5 inches (0.003793 m^3) change to the model to 3.5 inches (0.01039 m^3).

On the other hand, an increase in volume compression relates to pressure (PSI). Something beyond the objectives of this article can give a better understanding of magnetic filter operation and lifespan. Indeed, the 3.5-inch radius model would generate more pressure on the inside, but the structure has more metal and better welding points. It is not just about the change in diameter; it is also important to know the structure, heat capacity, rod amount, and number of cycles per shift.

Solution to Equation (10) would consider even the operation in real time, considering flow velocity and mass flux [12]. Finally, Equation (8) has a direct relation with the medium of the fluid, like the metal, and the space of the magnetic filter. Solutions for the last one can include heat capacity, gravity action by free fall, and finally a more general perspective of the dynamics.

5. Conclusion

Space and time variables are explicit parameters. For a long enough time, in an enclosed environment with a constant flow, collisions randomly point to the same original direction (or proportional to it) as they enter the filter. This implies that velocity for some particles or volume sections turns negative [13], making a second gradient and rotational in the opposite direction from the original. This is a consideration for future solutions and applications. At the factories, this constant flux is part of everyday production, increasing the pressure to the point that filters start leaking even on the best quality for sealing.

Explicit thermal effect is not analyzed [14–17]. It just mentioned the action of the fluid on the pipeline for the pressure as the average effect of the collision of molecules.

The whole model and equations were solved in weeks due to a deadline at the factory. For an industry R&D department, a month or year of projects means money loss. An approximation is enough to improve the data sheet of equipment sold and installed. Lifespan can be predicted with high accuracy once the physical dynamics inside the filters can be determined and studied. This is an advantage for companies, no matter if they sell magnetic filters or use them. The efficiency of every filter is related to the proper pressure determination to consider the time it works on conditions beyond the designed purpose on optimal conditions.

Tables show that varying the space for fluid implies a pressure increase. Volume reduction or expansion generates heating on the material, the fluid, and noisy vibration causing fractures. The kind of fluid is important [10,12,14–17]; according to density and viscosity is the fluid dynamics studied; the closer the values to water ones, the better the analysis. Most equations are solved under water properties considerations.

Science researchers, engineers, industry workers, and society must collaborate to get better technology for making production more efficient. Once research gives information about lifespan production under real conditions, it is possible to prioritize preventive maintenance over corrective maintenance. As part of lifespan prediction, regulating the mass flux is necessary to avoid mistakes in the quality process or damage to the structural integrity of the factory.

The tables make it clear that using water for quality tests expresses wrong values or something that is not useful for all processes. Factories should produce new brands of magnetic filters with other materials that can resist heating, vibration, mechanical torsion, and other effects occurring during the cleaning process.

No deeper analysis of the cleaning, manufacturing, and food processing kind of industry where this is applied.

6. List of symbols

A—cross section area of the pipeline, $[\mathrm{m}^2]$
B—bulk modulus of fluids, $[\frac{\mathrm{N}}{\mathrm{m}^2}]$
$\frac{D\omega}{Dt}$—Laplacian plus time derivative of the vorticity expression, $[\frac{1}{\mathrm{t}^2}]$
$\partial_i u_j$—sum of all derivatives (tensorial form) for space and time variables of the group velocity of fluid motion, $[\frac{\mathrm{m}}{\mathrm{s}^2}, \frac{1}{\mathrm{s}}]$
$\partial^2 \delta_{ij}$—sum of all second derivatives (tensorial form) for space and time variables of the perturbation on the system, $[\frac{\mathrm{N}}{\mathrm{m}^2}]$
F—force due to molecules collisions on the fluid, $[\mathrm{N} = \frac{\mathrm{kgm}}{\mathrm{s}^2}]$
g—gravity, $[\frac{\mathrm{m}}{\mathrm{s}^2}]$
H—mean height of the fluid while traveling, [m]
h_1—height at the pipeline before the fluid enters the filter, [m]
h_2—height at the pipeline after the fluid goes out the filter, [m]
L—expected length of pipeline, [m]
$\dot{m} = \rho VS$—mass flux, $[\mathrm{kgm}^2]$
m—mass of the fluid on the process during each cycle, [kg]
P—pressure at time *t*, $[\frac{\mathrm{N}}{\mathrm{m}^2}]$
ΔP—norm of the pressure on the filter, $[\frac{\mathrm{N}}{\mathrm{m}^2}]$
P_2—pressure on the filter due to rotational and gradient, $[\frac{\mathrm{N}}{\mathrm{m}^2}]$
P_3—pressure on the filter due to volume expansion, $[\frac{\mathrm{N}}{\mathrm{m}^2}]$
$Q = Av\cos\theta = Av = \sqrt{H/sL}$—mass flux, $[\frac{\mathrm{m}^3}{\mathrm{s}}]$
r_0—radius of the pipeline, [m]
r_2—radius of the magnetic filter, [m]
t—time, [s]
u_j—group velocity of the system inside the filter, $[\frac{\mathrm{m}}{\mathrm{s}}]$
v—velocity of the wave, $[\frac{\mathrm{m}}{\mathrm{s}}]$
v_1—velocity of the fluid on the pipeline, $[\frac{\mathrm{m}}{\mathrm{s}}]$
v_2—velocity of the fluid going out of the filter, $[\frac{\mathrm{m}}{\mathrm{s}}]$
ρ—density of the fluid, $[\frac{\mathrm{kg}}{\mathrm{m}^3}]$
$\omega = \nabla \times v$—vorticity inside the magnetic filter, $[\frac{1}{\mathrm{s}}]$
ω_0—natural frequency of the fluid inside the magnetic filter $[\frac{1}{\mathrm{s}}]$
V—volume of the fluid inside the magnetic filter, $[\mathrm{m}^3]$

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