

Research Article

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Experimental Investigation of a Centrifugal Pump Hydraulic Performance in Hydraulic Transmission of Solids

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Abstract: In petroleum and mine industries, the centrifugal pumps were used for transferring solid particles with water. This method is preferable to other methods because of its user friendly and economic issues. In this article by selecting a proper pump and designing test circuit, we conducted hydraulic tests for water and water mixture with solid particles. For this purpose, an experimental set-up of centrifugal pump with only water and water with solid particles was developed. Then by analyzing the test results and efficiency equation, optimal coefficients of head loss is provided to improve the pump efficiency during hydraulic transmission of solids. The experimental results of power consumption, head, and pressure difference measurements in solid–liquid systems are presented. The experimental set-up results are compared with simulation and numerical one, which show a good agreement with them. It reveals that by adding the solid particles and increasing the fluid density up to 15%, the consumed power increases by about 20%, which result in dropping the efficiency of hydraulic system up to 6%. Finally, the optimal components for developed cycle presented for evaluation the various configuration and hydraulic analysis of pure flow and flow with solid particles in various applications to enhance the most achievable efficiency.

Keywords: Centrifugal Pump; Experimental Hydraulic Performance; Multiphase flow density; Mixing, Power efficiency

1 Introduction

The human need for water and moving it from another point caused the man to fall idea to build a device that resolves this problem. The first examples of pumps in which driving force was supplied by humans or animals were made and used by the ancient Egyptians in the 17th century BC. They were able to pull water with reciprocating pumps from the earth at a depth of 91.5 m. Pump refers to a device that gives energy to the fluid and transfers it from one point to another. Pumps, in terms of the principles, are divided into three general categories: dynamic pump, positive displacement pumps, and special pumps.

Centrifugal slurry pumps are widely used in the oil sand industry, mining, ore processing, waste treatment, cement production, and other industries to move mixtures of solids and liquids. Wear of slurry pump components, caused by abrasive and erosive solid particles, is one of the main causes of reduction in the efficiency and useful life of these pumps. This leads to unscheduled outages that cost companies millions of dollars each year. The idea is to combine predictions of multiple classifiers to reduce the variance of the results so that they are less dependent on the specifics of a single classifier. This will also reduce the variance of the bias, because a combination of multiple classifiers may lead to a more expressive concept class than a single classifier [1]. In a clear contrast to the general performance of centrifugal slurry pumps in conventional solid–liquid systems, the total head height increased with an increase in the slurry solid mass content because of several reasons, including unique friction loss behavior (i.e., drag reducing feature) of fibrous particles slurries in pipelines. In addition, small-sized fibrous particles increased the efficiency of the pump more than that of the same pump handling pure water only. Different researches on slurry pumps are conducted at recent years [2–5]. The results can be used in the design and operation of centrifugal slurry pumps to transport fibrous agricultural residue biomass materials. However, the effects of other parameters such

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as air in the system and anaerobic problems should also be taken into account [2].

The theory analyses and numerical simulation were conducted on the internal two-phase flow of the pump. The distribution of the solid particles in impeller is observed, and the influence of impeller outlet angle on the efficiency of the pump and the ability of solid particles passing through is analyzed. The results showed that the solid particles concentrated on pressure surface of impeller. When the impeller outlet angle was higher, local medium energy lost seriously. When the angle was decreased, the blade was more suitable for the flow of the solid particles, which improved the impeller wearing and increased efficiency [6]. Researchers have performed some works on centrifugal pump casing because of slurry flow recently [7–10]. In [7], through summarization and comparison of the various phase discrimination methods, they proposed a two-phase identification method based on the statistics of gray-scale level and particle size. The assessment of performance through experimental PIV images shows a satisfying effect for particle identification. It confirmed that the algorithm proposed in the present study has good performance and reliability for PIV image processing of particle–fluid two-phase flow inside high-speed rotating centrifugal slurry pump.

A life cycle cost analysis model is developed in this study, to examine the effects of particle size distribution of the solid particles to be transported on the optimal sizing and lifetime of the pipelines used for the transportation of solid–liquid mixtures. The study shows interdependence of parameters such as the lifetime, the optimum diameter, the corresponding spacing for a given pumping power, and the particle size distribution of solid particles transported in the pipeline. Furthermore, the method used also provides the interrelation between the total length of pipeline when crushing is economical and the different particle size distributions [11]. Different researches on two-phase flow rotordynamic multiphase pump are conducted during the recent years [12–15]. In [12], different pumped two-phase flow cooling technologies for electronic components were presented. As the requirements for the heat dissipation of electronic components are growing, cooling technologies have evolved from air-cooled heat exchanger to technologies involving the use of single or two-phase refrigerants. Their research focused on three technologies that allow dissipation of heat flux more than 100 W/cm^2 : micro-channels, plate-fin, and spray cooling. Macroscopic, microscopic–nanoscopic, and hybrid heat enhancements for all three technologies are also presented.

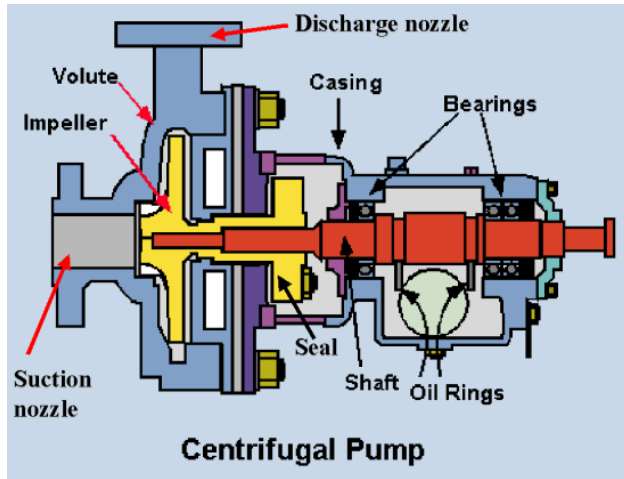
Turbulent suspensions of monodisperse coarse glass particles of 1 and 3 mm in diameter in water were numer-

ically simulated at their “just-suspended” speed N_{js} and at speeds above it, up to $2N_{js}$, in a vessel agitated by a down-pumping pitched-blade turbine. The solid concentration was in the range 5.2–20 wt%. The numerical results are compared to detailed 3D distributions of the three local-phase velocity components and solid concentration obtained by an accurate technique of positron emission particle tracking (PEPT). Increasing the agitation speed for up to $2N_{js}$ significantly reduces the normalized slip velocities. The results also indicate that there is no impact on the distributions of turbulent kinetic energy and Kolmogorov length scale. The eddy dissipation rate, however, is increasingly suppressed as solid concentration increases at N_{js} [16]. The hydraulic conveying of solid–liquid concentrated suspensions in pipelines corresponds to complex flows where particles with different sizes, concentrations, and flow velocities exhibit different flow regimes.

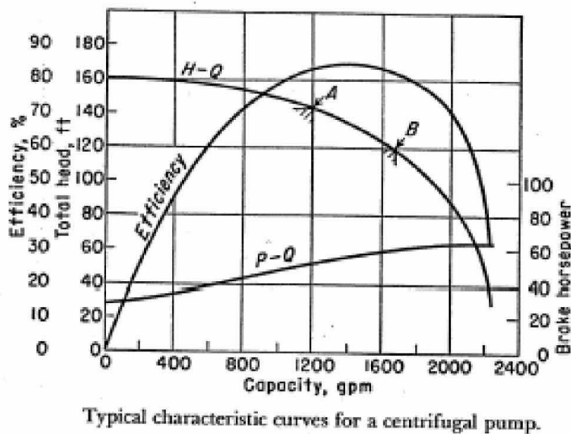
Recently, researchers have conducted some works on sewage sludge for pumping design [17–20]. The Gidaspow–Schiller–Neumann drag correlation was more adequate for low flow velocities and with intermediate particle concentrations. With this work, it is shown that using the same drag correlation for the numerical description of experimental data for highly concentrated settling solid–liquid flows does not adequately reproduce the different flow regimes [17].

The best designing point of a centrifugal pump is the part of the curve at which the efficiency of the pump is maximized. As the slope of the curve is high, changes in the pump head will cause greater deviation from the operating point. For example, in a pump with a Q–H curve with a slope flow changes, changes in head will be high, while in a pump with Q–H curve, relatively low gradient with the vast changes associated with the changes in head is low; thus the use of each of them depends on operating conditions. Characteristic curves of centrifugal pumps have relatively small slope, and their maximum efficiency is in the average pump capacity range and power consumption to increase to the point of work or possibly even beyond. An example of the characteristic curves is given in Figure 1 [21, 22].

Slurry pump is pumping the slurry and corrosive materials, sand, chemical waste, rubbish of device, and so on. The pumps usually transport solids between 8 and 400 mesh networks. Sand pump transports solid. Many slurry and sand pumps are covered with plastic. Impeller used in this type of pump is a semi-open impeller, and if the distance between the impeller and the body becomes much more, it will decrease the pressure or flow pump.



(a)



(b)

Figure 1: Centrifugal pumps: (a) components and structure and (b) characteristic curve [21]

1.1 Hydraulic transport of solids

Granular materials such as sand, gravel, coal, minerals, and ash can be transferred in the form of a suspension of carrier fluid (mostly water) in pipelines. Economically, this is especially interesting when the material is transferred as suspension because of mining methods, mining or production, processing it. Centrifugal pumps are very convenient for the transport of solids. They are used, for example, in the mining industry, to pump ash in power plants, as dredging pumps, and for the removal of flue gas desulfurization facilities. Hydraulic solids transfer pumps (also known as slurry pumps) have two phases because these pumps transfer solid and liquid phases. Basically, the main considerations are applicable in previous years with the important difference that both phases are rela-

tively incompressible. Solid phase can absorb energy only in the form of kinetic energy, and it can store the energy for phase static pressure. In hydraulic transport of solids, density ratio p_s/p is significantly less for liquid pumping gas mixtures: almost 1.5 for coal, about 2.7 for sand, and 5 for minerals. Consequently, detachment phenomena are much weaker than the liquefied petroleum gas flows. However, the separation obeys the laws, because pathways for solid particles are determined by centrifugal force, Coriolis, movement, and stretching. In radial impellers, large particles, because of the Coriolis force, push the blades move up to the surface, while smaller particles move to the suction surface. It is also due to the inertia of coarse grains. Consequently, the wear on the impeller outlet especially in the blade pressure level is severe; downstream of the impeller moves in coarse grains spiral in coverage because of its inertia moves in tangential directions. The particle motion is strongly influenced by the elasticity of the particle that moves relative to the carrier fluid. When a particle moves with velocity $w_{s,0}$ in a liquid that is detectable; $w_{s,0}$ can be calculated using the following equation [23]:

$$w_{s,0} = \sqrt{\frac{4gd_s}{3\xi_w} \left(\frac{p_s}{p} - 1 \right)} \quad (1)$$

Owing to density differences between solids and liquids, the current paths of the particles diverted from fluid flow lines. The resulting transverse movement by moving exchange between solid and liquid phases leads to more wastage. Because of vibration and friction between particles and solid walls (input, impellers, and involutes), waste is created. As a result, water load and efficiency lock up compared to water pumping. This loss can be described as experimental factors that apply to the operation of water pumps. Additional drops with increasing concentration of solid particles increases density ratio p_s/p and grain size because the detachment tendency increases with these parameters. The results of experiments have been published that they used to calculate the correlation between the loss of water and solids derived hydraulic transfer efficiency. Differences in the solid-liquid mixture, test conditions, and specific rate suggested correlations diverge considerably from each other. Calculation of theoretical models has been developed [24–26]. For example, reduction of the head resulted in an increase in the slip by solid particles and further loss caused by impact and friction particles in the impeller and volute. This calculation produces similar results for empirical correlations. Therefore, investigating the effect of various parameters on hydraulic head exert appear to be appropriate [27].



Figure 5: A view of the tested impeller and the pump casing

ing sand blast are tested, which has a density of $1,672.75 \text{ m}^3/\text{kg}$.

2.3 Tested pump

Tested pump is an available pump in the industry; we have chosen one of the pumps of Navid Sahand Pump with ETA 32-160 code, 168mm license code, and two speed, 1450 and 2900 rpm. Because they have an appropriate hydraulic property for this test and has an iron helical impeller resistant against pressure and friction, we have used this for our test. Three pumps KRT 50-150 F were used as mixers in tanks and circle; it should be noted that the two pumps KRT 50-150F that were used as mixers in tanks with semi-open impeller without volutes.

AC electromotor 132M2B model is a product of Motogen Company; its specifications are presented in Table 1.

Large tank with a dimension of $200 \text{ cm} \times 100 \text{ cm} \times 200 \text{ cm}$ is used, according to that standard, temperature of the fluid used in closed circuit during the testing process should be between 0°C and 40°C ; therefore, by selecting this large tank, you do not need to use a heat exchanger to control the temperature of the fluid, and small tank with a dimension of $20 \text{ cm} \times 66 \text{ cm} \times 100 \text{ cm}$ are suitable for testing.



Figure 6: The semi-open impeller and pump used to mix the ingredients in the tank

Table 1: Electromotor specifications

Nominal load speed	2900 rpm
Output power	7.5 kw
Voltage rating	380Δ/660 Y
Flow rating	15.6Δ/9 Y
Power factor	$\cos \varphi = 0.85$
Efficiency	83%
Number of poles	2
Slip	0.02



Figure 7: Large slurry tank with blender pumps

According to the existing facilities, different types of ultrasonic flow meter (Model DFM4,0, products of Greyline Company) are used; for performing a special test, we had to use the exact technique of passing fluid at a specified time because exciting solid particles within the fluid can cause considerable error in the development of other methods.

In buoyancy: Borden tube manometer Model 10 and 111 (0–500 kPa) of WIKA group of companies, which was designed by En 837-1, with an accuracy class of 2.5 was used.

In suction: At this point, because we have positive pressure and pressure curve, we used a manometer for both positive pressure and the type of curve records that. Borden tube (-100 ± 100 kPa) UGB-F122N of Dwyer Company with an accuracy of 2.5% was used.

2.4 Instructions of test the pump

To do the test to identify if any solid particles present inside the tank, large tank that is equipped with two pumps KRT 50-150F without involute was stirred for 30 min to create a homogeneous mixture without settling. Then the pump inlet valve is fully opened to allow the fluid to flow at the pump. In this case, we just pause the system that had become stable to record quantities such as the pressure, head, flow rate, voltage, and power. The next step is to record the rate that has reached a stable state after the pump, we calculate the amount of fluid passing in registered specified time with stopwatch and we calculate the flow rate; because of potential errors resulting from the rates calculated in this way, to record the rates, repeat this step three times and then with the average measurement, we recorded the best mode. Then while the inlet valve is still fully open, we open outlet valve a little more to flow high flow rate; after the stabilization of the system, we again note the above quantities with rate; we repeat the process for eight times (a total of 24 times) to open the outlet valve for any desired specific gravity.

2.5 Measurements accuracy

According to the standard [28] ISO 9906: 2000, measurements have the necessary precision if the following three conditions are met:

- Distribution speed is symmetric about stream axis.
- Static pressure distribution in the cross section of the measurement is monotonous.
- There is no rotation of the flow of the circuit elements in the measurement location.

Stability test conditions call when the average value of the whole quantity of flow rate, total head pump, input power, and rotational speed is independent of time. In practice, the permissible difference between the largest and smallest readings and the average value for a committee of rate, total head, and pump input power is up to 1.2%, and for rotational speed, it is 0.4%, at least 10 seconds can be accepted as a permanent condition.

2.6 Standard deviation

In probability and statistics, the standard deviation is a measure of the dispersion of a probability distribution or random variable and representative values around the mean value is dispersion. Standard deviation usually show with. The standard deviation equal to the square root of the variance is defined and obtained from the following equation:

$$\sigma = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \quad (2)$$

In this relation, \bar{x} is average data that is calculated from the following equation:

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_{11}}{n} \quad (3)$$

2.7 Measurement errors

A kind of error that is known as systematic error partly depends on the measuring equipment and measurement methods and occurs in one direction. This type of error does not disappear with repeated measurements (Table 2).

Table 2: Permissible values of systematic error [28]

Permissible values (percent)	Quantity
2.5	Flow rate
1.4	Rotational speed
2.5	Total head pump
2.0	Input power

Another type of error is called accidental or random error. When a measurement is repeated and the results are different so that the difference of the mean value is positive or negative numbers, in this case, measurement errors is random type. This type of error can be detected by repetition. The overall error is equal to the square of the sum of squares of systematic error and random error. The overall error allowed values in the tests of the pump, according to the standard ISO 9906: 2000 in Table 3.

Table 3: Permissible values of overall error [28]

Sign	Allowable error (%)	Parameter
ℓ_o	$3.5 \pm$	Flow
ℓ_n	$2 \pm$	Rotational speed
ℓ_H	$5.5 \pm$	Total Head
ℓ_{pyr}	$5.5 \pm$	Actuator input power
ℓ_P	$4 \pm$	Pump Input power
ℓ_N	$4.6 \pm$	Efficiency

3 Result

3.1 Results related to S.G. = 1, pure water

In the first phase, the testing with pure water was done with the 8 point something different, and each point is repeated thrice and the average of the data obtained for the parameters are given in Table 4. The flow rate within the specified time was analyzed by an ultrasonic flow meter that is connected to the outer pipe and acts in pure water without defects, with less than 2% error rate data to be confirmed.

3.2 Results related to fluid S.G. = 1.05

In the next step, the desired parameters in relation to hydraulic transmission pulp (slurry s) to a specified amount of mixtures of solids and liquids (slurry) in 1 m^3 is calculated and then using equations and terms developed for each of four modes (S.G. = 1, 1.05, 1.1, 1.15), we obtain different values of parameters, and as to obtain reliable values with fewer errors in each operating point, we repeat the experiment thrice and obtain the average; now we do calculations related to S.G. = 1.05 for 1 m^3 slurry mixture. So we identify the necessary amount of fluid and solid to perform the test.

$$\begin{cases} V_s + V_w = 1 \text{ m}^3 \\ m_s + m_w = 1,050 \text{ kg} \end{cases} \quad (4)$$

$$\begin{cases} m_s = \rho_{ss} V_s = 1672.75 V_s \\ m_w = \rho_w V_w = 998 V_w \end{cases} \quad (5)$$

$$V_w = 1 - V_s \quad (6)$$

For convenience, a better index of the volume or weight of liquid and solid particles by weight or volume

can be obtained with a simple proportion to the amount of solid particles for a certain amount of fluid with a volume of 1 m^3 in mode of S.G. = 1.05.

$$\frac{\text{Solid} \rightarrow 128.8 \text{ kg}}{\text{Water} \rightarrow 921.15} = \frac{x_{\text{kg}}}{998 \text{ kg}} \rightarrow x = 139.544 \text{ kg}_{\text{solid}}$$

$$\text{S.G.} = 1.05.$$

As a result, for the first case, the solid particles S.G. = 1.05, we have

$$\begin{aligned} m_w &= 998 \text{ kg} & m_s &= 139.544 \text{ kg} \\ V_w &= 1 \text{ m}^3 & V_s &= 0.083 \text{ m}^3 \end{aligned}$$

Other relevant parameters:

$$C_V = \frac{p_{\text{mix}} - p}{p_s - p} = \frac{V_s}{V_{\text{mix}}} = \frac{0.083}{1.083} = 7.66\%$$

$$C_m = \frac{Q_s}{Q + Q_s} = \frac{m_s}{m_{\text{mix}}} = \frac{139.544}{1137.54} = 12.267\%$$

It should be noted that the head, hydraulic power, and yields are obtained in the following formula.

$$\eta = \frac{P_{\text{hyd}}}{P_{\text{motor}}}$$

$$H_p = \frac{p_2 - p_1}{\rho g} + \frac{v_2^2 - v_1^2}{2g} + (z_2 - z_1) + \Delta h$$

$$P_{\text{hyd}} = \gamma H Q = \rho g H Q$$

For example, in the case of S.G. = 1.05 and point 5 are

$P_{\text{Discharge}} = 296.5 \text{ kPa}$, $P_{\text{suction}} = -9.5 \text{ kPa}$, $Q = 24.77 \text{ m}^3/\text{h}$.

To calculate the pump head due to the input and output is the same diameter, so $V_2 = V_1$. The height difference between the two pressure gauges in the inlet and outlet is equal to $Z_2 - Z_1 = 0.25(\text{m})$ and the temperature of water is 20°C so if ignore from the loss of hydraulic fluid from the pump path will be

$$\begin{aligned} H_p &= \frac{p_2 - p_1}{\rho g} + \frac{v_2^2 - v_1^2}{2g} + (z_2 - z_1) + \Delta h \\ &= \frac{(296.5 - (-9.5)) \times 1000}{1050 \times 9.8} + 0.25 = 29.98(\text{m}) \end{aligned}$$

And about hydraulic power, we have

$$\begin{aligned} P_{\text{hyd}} &= \gamma H Q = \rho g H Q = 1050 \times 9.8 \times 29.98 \times \frac{24.77}{3600} \\ &= 2122.6115 \text{ w} = 2.122 \text{ Kw} \end{aligned}$$

$$\eta = \frac{P_{\text{hyd}}}{P_{\text{motor}}} = \frac{2.122}{3.54} \times 100 = 59.94.$$

Now, the values mixture prepared in accordance with the instructions given to register are obtained and have been included in Table 5.

Table 4: Results related to S.G. = 1, pure water

	1	2	3	4	5	6	7	8
$Q(m^3/h)$	0	17.38	20.36	23.16	24.86	25.73	27.14	29.77
$H(m_{h2o})$	41.914	38.131	34.96	31.98	30	28.01	24.99	21.97
$P_M(Kw)$	1.5	2.99	3.1	3.29	3.33	3.43	3.51	3.57
$P_H(Kw)$	0	1.008	1.933	2.01	2.026	1.957	1.842	1.776
$P_{Discharge}$	417.5	370.5	334.5	302.5	281	259.5	224	192.5
$P_{suction}$	10	0	-5	-8	-10	-12	-18	-20
P_D-P_S	407.5	370.5	339.5	310.5	291	271.5	242	212.5
Efficiency	0	60.2	62.35	61.09	60.84	57.05	52.47	49.74

Table 5: Results of the state S.A. = 1.05, Cm = 12.26%, Cv = 7.66%

	1	2	3	4	5	6	7	8
$Q(m^3/h)$	0	17.1	20.25	22.85	24.77	25.72	27.65	29.84
$H(m_{h2o})$	41.98	38.01	34.94	31.97	29.98	28.01	25.03	21.96
$P_M(Kw)$	1.5	3.24	3.31	3.43	3.54	3.63	3.85	3.91
$P_H(Kw)$	0	1.862	2.022	2.088	2.122	2.059	1.978	1.873
$P_{Discharge}$	440	389	352	319	296.5	274	238	204.5
$P_{suction}$	10.5	0.5	-5	-7.5	-9.5	-11.5	-17	-19
P_D-P_S	430.5	388.5	357	326.5	306	285.5	255	223.5
Efficiency	0	57.46	61.08	60.87	59.54	56.72	51.37	47.9

Table 6: Results related to S.G. = 1.1, Cm = 22.98%, Cv = 15.11%

	1	2	3	4	5	6	7	8
$Q(m^3/h)$	0	16.8	20.14	22.76	24.79	25.65	26.98	29.45
$H(m_{h2o})$	41.99	38	34.99	31.97	29.98	28.07	24.97	22
$P_M(Kw)$	1.5	3.39	3.53	3.66	3.83	3.87	3.96	4.16
$P_H(Kw)$	0	1.911	2.11	2.178	2.22	2.155	2.017	1.94
$P_{Discharge}$	461	408	370	334.5	311.5	289	250	216.5
$P_{suction}$	11	1	-4.5	-7.5	-9	-11	-16.5	-18
P_D-P_S	472	409	374.5	342	320.5	300	266.5	234.5
Efficiency	0	56.37	59.77	59.5	57.96	55.56	50.93	46.63

3.3 Results related to fluid S.G. = 1.1

Next, the calculation related to S.G. = 1.1 was performed, but at this stage, while doing calculations that determine the amount of fluid from the previous stage and excited into the reservoir, it means that

$$\begin{cases} m_W = 198 \text{ kg} \\ V_W = 1 \text{ m}^3 \end{cases}.$$

It should be noted that the amount of solid in the tank is 139.544 kg with 1 m³ of liquid water; as a result, in the second step, should be to add value 158.352 kg in the solid particles sandblasting the tank and taking action according to our data, the results are given in Table 6.

3.4 Results related to fluid S.G. = 1.15

In the final stage of S.G. = 1.15 outflow discharge mode and relevant parameters, given that there is 998 kg of liquid water and 297.89 kg of sand solid particles in the tank, we obtain the following:

$$\begin{cases} m_W = 998 \text{ kg} \\ V_W = 1 \text{ m}^3 \end{cases}.$$

And as we know that the amount of solid particles present in the tank before the previous mode S.G. = 1.1 is 297.89 kg, as a result, after adding 188.49 kg, abraded particles continue to seek testing and the results of the tests are recorded in Table 7.

According to the measured and calculated values in Table 7 in different modes and different specific gravities,

Table 7: Results related to S.G. = 1.15, Cm = 32.76%, and Cv = 22.48%

	1	2	3	4	5	6	7	8
$Q(m^3/h)$	0	16.4	20.09	22.97	24.68	25.59	27.09	29.65
$H(m_{h2o})$	41.99	38	35.07	32.01	29.97	28.02	25	21.98
$P_M(Kw)$	1.5	3.48	3.69	3.9	4.05	4.07	4.15	4.36
$P_H(Kw)$	0	1.95	2.205	2.301	2.315	2.24	2.12	2.04
$P_{Discharge}$	482	426.5	388	351	326.5	302.5	263.5	227.5
$P_{suction}$	11.5	1	-4.5	-7	-8.5	-10.5	-15.5	-17.5
$P_D \cdot P_S$	493.5	427.5	392.5	358	335	312.5	279	245
Efficiency	0	56.03	59.75	59.01	57.16	55.03	51.08	46.78

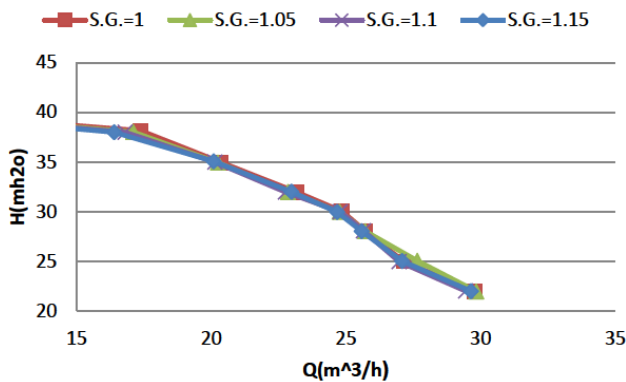


Figure 8: Head-rate comparison chart in four different specific gravities

the curve of head-rate, hydraulic power pumps-rate, electromotor power consumption-rate, pump efficiency-rate, and pressure difference-rate can be plotted and the charts are shown in Figures 8–10.

As can be seen in Figure 8, tested hydraulic behavior in the presence of solid particles of the head and rate was almost constant, had no little change, and had maintained continuity and its slope of normal (negative), and we can say that solid particles has no significant effects on the behavior of the pump head in different rate, and this means that, as stated by Gulich *et al.*, and according to their tests in cases where the diameter (ds) of the particles are more than 100 μm and the fluid slurry has the suspended particles with high sedimentation property, shortly it like to be homogenized usually show that behave as non-viscous and Newtonian fluid [29] that this is the truth about the behavior of the fluid slurry tested and corresponding graph. As the two charts (Figures 9 and 10) that relates to specified power and according to Mr. Kouidri and colleagues, exciting solid particles in a carrier fluid and the fluid density changes can have a significant impact on the power requirements of electromotor pumps for the transfer and subsequent power consumption [30] and given this

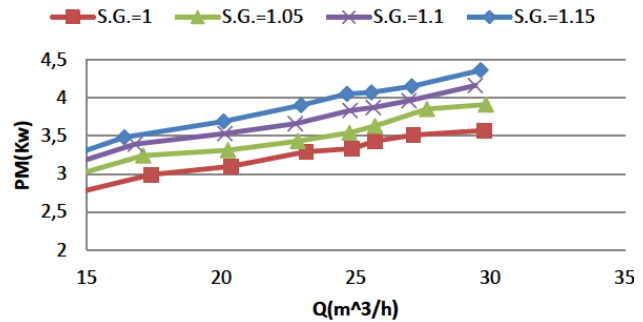


Figure 9: Electromotor power consumption-rate chart in four different specific gravities

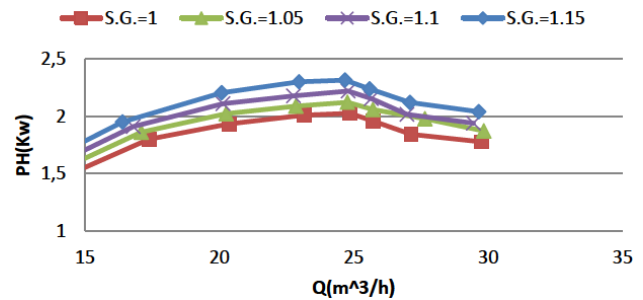


Figure 10: Hydraulic power pumps-rate chart in four different specific gravities

change in behavior analysis of electromotor power, you can even guess and predict the solid particles transferred and even the density of the slurry.

Owing to the presence of solid particles in the fluid slurry, blasting creates friction between the wall of the pump impeller and impacts the particles in the fluid passage when passing through the passage, as you can see, power consumption is directly proportional to the power requirements and power consumption of the electromotor pump and the level of solid particles increases, and thus as the density of the fluid rises, power also increases.

It should also be noted that, according to Kouidri *et al.*, during tests, there were changes in the density of the

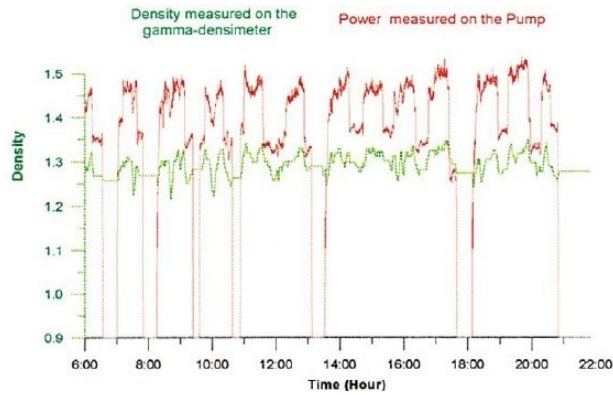


Figure 11: Comparison of the measured density by gamma method and the amount of power consumption

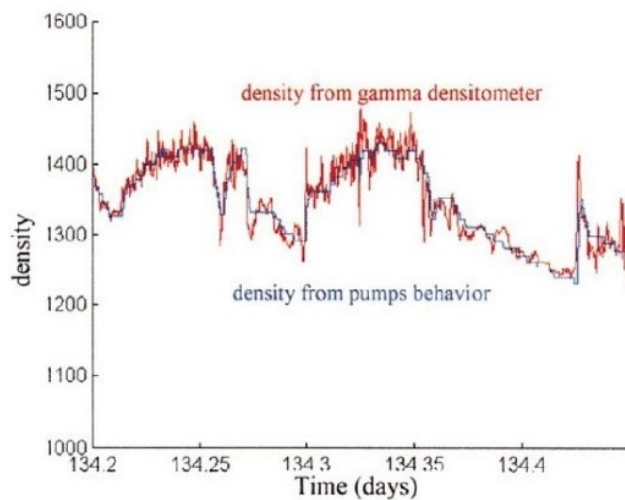


Figure 12: Comparison of the measured density by gamma and power method

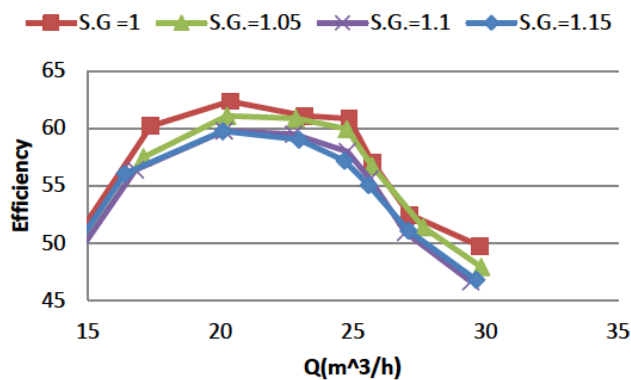


Figure 13: Pump efficiency–rate chart in four different specific gravities

transition from the pump at different times when different amounts of solid particles pass from the pumps [30]. Accordingly, fluctuations were quite evident, and such be-

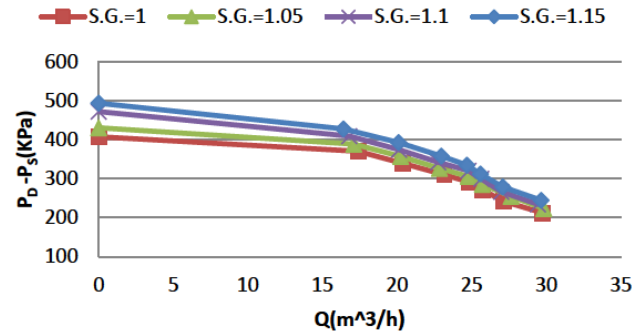


Figure 14: Pressure difference – rate chart in four different specific gravities

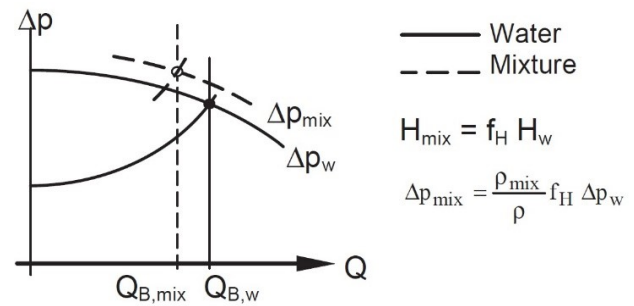


Figure 15: Chart of pressure difference according to rate from the results of Wilson [31]

havior was recorded by the control room of electromotor power.

With regards to the relationship of the ratio of output power or useful or hydraulic pump efficiency compared to the input power of electromotor and regardless of losses, such as coupling between pump and motor, can be seen returns purified water that was done in the first phase Located at the top of the charts and the specific gravity of the fluid slurry increases, efficiency decreases but as you can see B.E.P. And general order charts is maintained. And the nature of this behavior is due to the same reason mentioned earlier that by increasing the amount of particles passing through the passage pump impeller, the friction increases, also blows the particles to the impeller increases, and the fluid moves slowly through the passage and losses its actions by the particles present in the pump, resulting in reduced efficiency of the pump by increasing and decreasing the specific gravity of the fluid particle slurry and as we continue to find the best yields in rate almost 20 m³/h remained, and also as we see, the results obtained by Gulich and colleagues [29] are reasonable and approved, and a drop in efficiency is shown to match with the hydraulic transfer of solid particles.

According to the results obtained by Wilson and colleagues [31], it was observed that the solid particles can

make a difference in the pressure than pure water scenarios, and as observed from the test results, as expected, the increased difference in pressure, which naturally according to the formula also this increases of pressure difference in the presence of solid particles is acceptable.

4 Conclusion

In this research, we examined the role of solid particles in the hydraulically operated centrifuge pumps in different special gravity and the relevant parameters such as rate, head, power pumps, electromotor power consumption, efficiency and pressure. However, regarding the difference in density between the solid and liquid particles of flow lines inside impeller and diffuser passage, just not as liquid and because of changes in mixtures and liquid momentum, hydraulic losses will increase at the pump and will break down the curve of head–rate and power–rate and efficiency–rate that designed for water. Of course, there will be additional losses because of shock and friction of particles and the walls of the pump. So, by examining the presence of solid particles in the fluid, the results obtained were summarized as follows:

1. Existence of solid particles in the fluid has important effect on the power consumption of the pump, and the electromotor input power is proportional to the number S.G.
2. Reduction in pump efficiency in the presence of solid particles in the fluid slurry is proportional to the increase in specific gravity
3. There is no change in the behavior and overall shape of the yield curve according to rate and point B.E.P.
4. More high pressure is created in the presence of solid particles in the fluid compared to pure water
5. No significant change in the pump head at different flow rates was observed in the presence of sandblasting solid particles
6. The ability to predict the density of the fluid and the solid particles passing through the pump is based on the behavior and changes in electromotor power consumption.

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