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Review Article

# Performance Characteristics of Nanofluid Pump

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## Abstract

This study was prompted by the fact that nanofluid exhibits a completely different behavior from the base fluid, usually water. It was expected that there should be a reduction in the pumping power when pumping nanofluids as compared to pure liquids, without nanofluids. Pump action and their performance are defined in terms of their characteristic curves. These curves usually supplied by pump manufacturers are for water only. This research reveals performance curves for nanofluid and compares it with those obtained for water. By pumping separate concentrations of copper nanofluids which contains 5g, 10g, 15g and 20g of copper nanoparticles, through a constructed nanofluid pump testing machine, the various flow parameters obtained were used to characterize a one horse power centrifugal pump. The flow parameters included; time to pump 2.5, 5.0, and 7.5 liters of copper nanofluids, flow rate, head gained, Pump vibration due to pumping activities, pump speed, fluid power, brake power and the pump efficiencies. These parameters were used to plot performance characteristics curves for the different copper nanofluid concentrations which were then compared with those obtained for ordinary water. The results show a reduction in the pumping power as compared to pure liquids, without nanofluids. The performance characteristic curve obtained for water when compared to those obtained for copper nanofluids, revealed that there was an increased in pump efficiency at lower concentration of the copper nanofluid. Lastly, the relevance of the distinct properties of nanofluids to exhibit enhanced thermal conductivity and convective heat transfer coefficient compared to the base fluid was established.

**Keywords:** Nanofluid, Pumps, Nanomaterials, Pump Horse Power, Brake horse power and efficiency.



## 1. INTRODUCTION

A nanometre is one-billionth of a meter. Nanotechnology is the manipulation of matter on an atomic and molecular scale [1]. It deals with control and manipulation of matter at the level of about 1 to 100 nm in order to create new materials, devices and systems with fundamentally new properties and functions [2]. The physicist Nobel laureate, Richard Feynman was the first scientist to suggest (in 1959) that devices and materials could someday be fabricated to atomic size specifications [2].

Colloidal dispersions of nanometer-sized particles (nanomaterials) in a base fluid, popularly known as nanofluids, have been observed to exhibit enhanced thermal properties, amongst them; higher thermal conductivity and heat transfer coefficients compared to the base fluid [3]. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil [4].

Nanomaterials are an increasing important product of nanotechnologies [5, 6]. They contain nanoparticles smaller than 100 nanometres in at least one dimension. Nanomaterials have structural features in between those of atoms and bulk materials and have at least one dimension in the nanometer range [7]. They utilize the well-established solid state structure bonding such as ionic, covalent and metallic. The theory for transition in energy levels from discrete for fundamental elements to continuous bands for bulk is the basis of many electronic properties [7].

Nanomaterials exhibit very interesting size dependent electrical, optical, magnetic and chemical properties compared to their bulk counterparts. This is mainly due:

i. Large fraction of surface atoms;
ii. High surface energy;
iii. Spatial confinement and
iv. Reduced imperfections [7].

Nanofluid is a new kind of heat transfer medium [8], with an increasing level of importance. For instance, the simulations of the cooling system of a large truck engine indicate that replacement of the conventional engine coolant (ethylene glycol-water mixture) by a nanofluid would provide considerable benefits by removing more heat from the engine. Additionally, a calculation has shown that a graphite based nanofluid developed jointly by Argonne and Valvoline, could be used to eliminate one heat exchanger for cooling power electronics in a hybrid electric vehicle. This would obviously reduce weight, and allow the power electronics to operate more efficiently. The benefits for transportation would be [9]:

- Radiator size reduction
- Pump size
- Possible of elimination of one heat exchanger for hybrid-electric vehicles
- Increased fuel efficiency

Nanofluids have distinct properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, and hybrid-powered engines [10], engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, nuclear reactor coolant, in grinding, machining, in space technology, defense and ships, and in boiler flue gas temperature reduction. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid [11].

The aim of this research work is to determine the performance characteristics and curves of a centrifugal pump using nanofluid as the pumping fluid and comparing with those obtained for water. This will reveal the effect of nanofluid on the performance of centrifugal pump and it consequence pumping applications.

The specific objectives include;

1. To prepare a nanofluid solution use to evaluate the centrifugal pump performance characteristics.
2. To construct a nanofluid pump testing machines to determine fluid quantities such as flow rate (Q), head (H), power (P), speed (N), size (D) and efficiency (η).
3. To plot nanofluid pump performance characteristic curves.
4. To compare the nanofluid pump performance characteristic curves with those of water.
5. To establish the impact of nanomaterials on the performance of centrifugal pump.

Nanofluids possess the following advantages [12]

1. High specific surface area and therefore more heat transfer surface between particles and fluids.
2. High dispersion stability with predominant Brownian motion of particles.
3. Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
4. Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.
5. Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.

## 2. Problem Formulation

The fluid quantities involved in all hydraulic machines are the flow rates (Q) and the head (H), whereas the mechanical quantities associated with the machine itself are the power (P), speed (N), size (D) and efficiency (η) [13].

### 2.1. Performance Characteristics of Pumps

The output of a pump running at a given speed is the flow rate delivered by it and the head developed. Thus, a plot of head and flow rate at a given speed forms the fundamental performance characteristic of a pump. In order to achieve this performance, a power input is required which involves efficiency of energy transfer. Its value is not fixed for a given pump [14]. Thus, it is useful to plot also the power, P and the efficiency, η against flow rate, Q [15].

Overall efficiency of a pump (η) = Fluid power output / Power input to the shaft
= ρgHQ / P

Where ρ = density,

It was expected that there should be a reduction in the pumping power when pumping nanofluids as compared to pure liquids, without nanofluids.

### 2.1.1 Pump Performance Characteristic Curves

Pump action and the performance of a pump are defined in terms of their characteristic curves. These curves correlate the capacity of the pump in unit volume per unit time versus discharge or differential pressures. These curves usually supplied by pump manufacturers are for water only [15].

These curves usually show the following relationships (for centrifugal pump) [16].

1. A plot of differential head versus capacity. The differential head is the difference in pressure between the suction and discharge.

2. The pump efficiency as a percentage versus capacity.
3. The break horsepower of the pump versus capacity.

**3. Problem Solution**

A fine mixture of copper nanofluid was produced through the two step process [17] copper nanoparticles was added and continuously stirred in water with a magnetic stirrer for about 30 minutes. This was stirred in separate quantities of 5g in four measuring beakers as shown in the Figure 1.

**Fig 1: Copper nanofluid derived after stirring copper nanoparticles in water**

A Nanofluid pump test machine used to characterize a one horse power centrifugal pump was constructed. It is as described in figure 2 and figure 3. It consist of the following components:

- Frame
- Reservoir Tank
- Volumetric Measuring Tank
- Pump
- Connecting Pipes

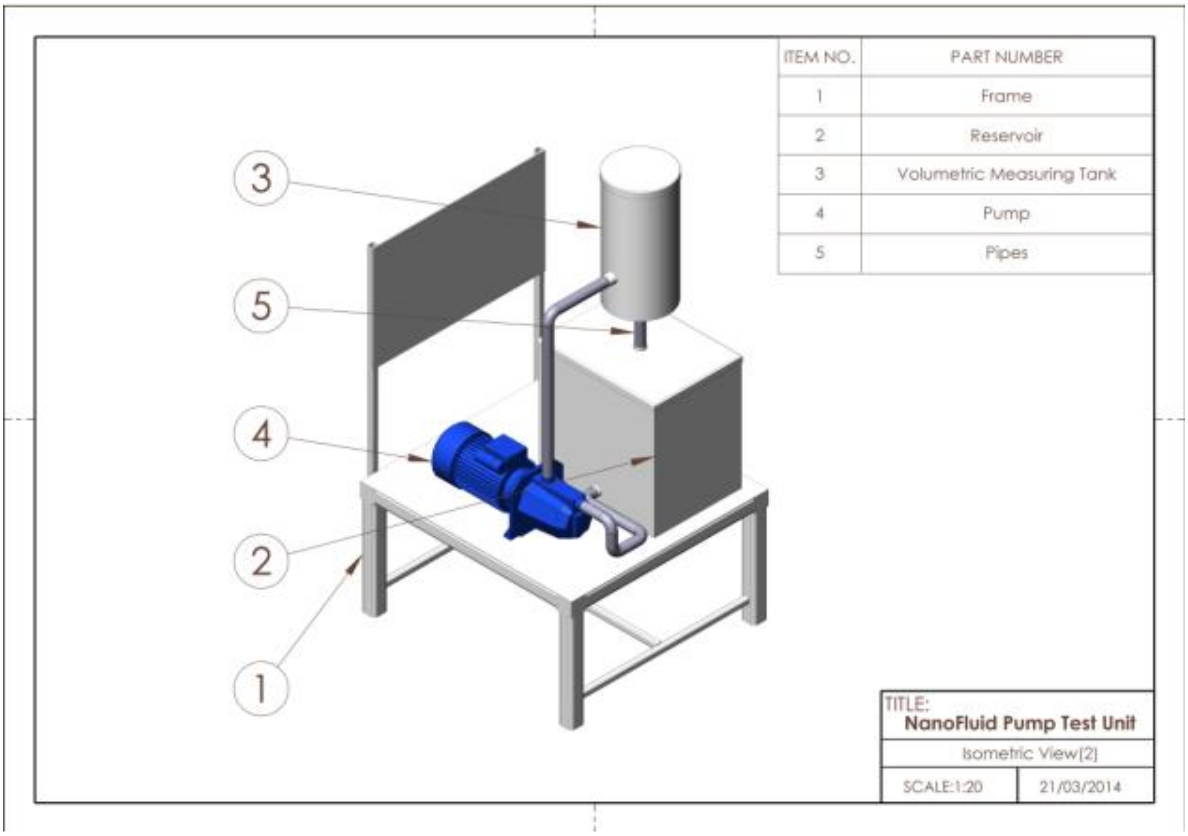


**Fig 2: Nanofluid Pump Test Unit (Isometric View)**

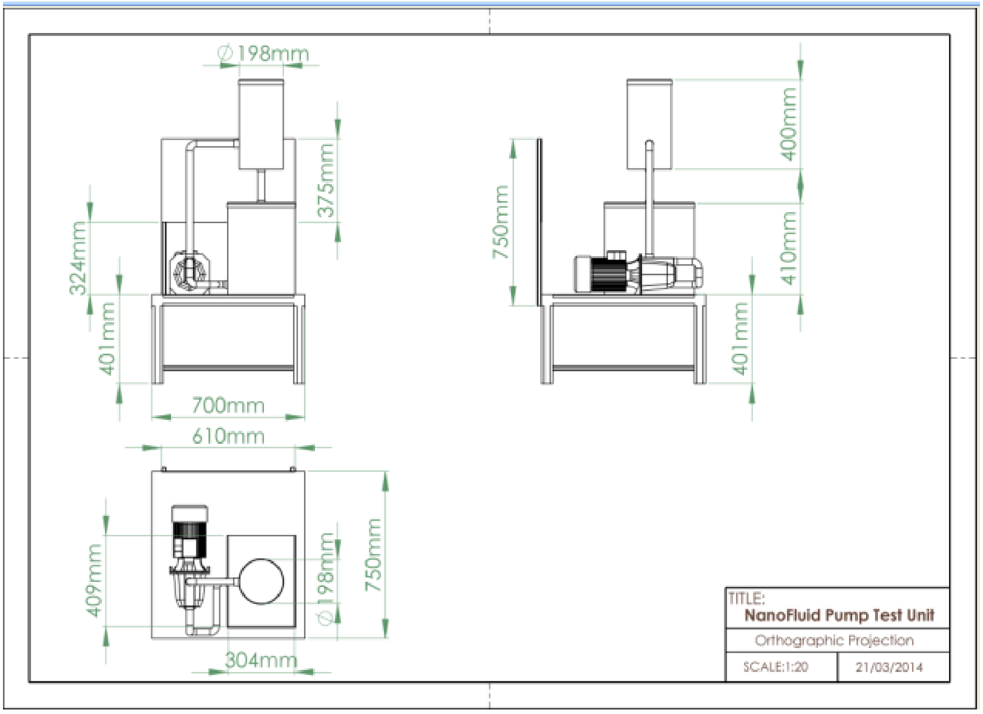


**Fig 3: Nanofluid Pump Test Unit (Orthographic Projection)**

### 3.1 Performance Characteristics of Pumps

The pump characteristics were obtained by carefully following the following procedures below, figure 4:

1. The stirred 5g of mixed copper nanofluid was added to 20 litres of water in the reservoir tank. The pumping machine was then connected to a power source.
2. The delivery valve was gradually adjusted with the stop watch started simultaneously.
3. The time it took to pump 2.5 litres, 5 litres, and 7.5 litres was measured and recorded.
4. The volume flow rate for each particle flow was noted and recorded.
5. The pressure gauge deflection due to pumping activities was noted and recorded.
6. The pump vibration was measured with the aid of a vibration meter. Thus, the pump speed was evaluated.
7. The head rise due to pumping was noted and recorded.
8. The mass of the copper nanofluid in the reservoir was increased to 10g by adding an additional 5g to it. Thus, increasing the copper concentration in the system.
9. Steps 2 – 7, were repeated for this concentration.
10. The mass of the copper nanofluid in the reservoir was increased to 15g by adding an additional 5g to it. Thus, increasing the copper concentration in the system.
11. Similarly, Steps 2 – 7, were repeated for this concentration.
12. Lastly, the mass of the copper nanofluid in the reservoir was increased to 20g by adding an additional 5g to it. Thus, increasing the copper concentration in the system with Steps 2 – 7 being repeated.

**Fig 4: Nanofluid Pump Test Machine (Experimental Set-up)**

**Table 1: Pressure Rise (PR), Pump Speed (PS), Head Gained (HG), Time (T), Flowrate (FR) [/1000], Nanofluid Power (NFP), Brake power (BP) and Efficiency (E) obtained without Nanofluids**

| PR (bar) | PS (rev/s) | HG (m) | T (s) | FR ($m^3/s$) | NP (Kw) | BP (Kw) | E |
|---|---|---|---|---|---|---|---|
| 3.8 | | 0.18 | 23.02 | 0.434 | 0.047 | 0.076 | 0.619 |
| 4.2 | 462.5 | 0.34 | 35.49 | 0.282 | 0.066 | 0.11 | 0.58 |
| 4.8 | 528.9 | 0.41 | 102.2 | 0.095 | 0.031 | 0.56 | 0.55 |

 

**Table 2: Pressure Rise (PR), Pump Speed (PS), Head Gained (HG), Time (T), Flowrate (FR) [/1000], Nanofluid Power (NFP), Brake power (BP) and Efficiency (E) obtained with 5g of Nanofluids**

| PR (bar) | PS (rev/s) | HG (m) | T (s) | FR ($m^3/s$) | NP (Kw) | BP (Kw) | E |
|---|---|---|---|---|---|---|---|
| 3.8 | 45.2 | 0.17 | 21.59 | 0.463 | 0.0499 | 0.0723 | 0.689 |
| 4.2 | 54.2 | 0.33 | 35.01 | 0.285 | 0.067 | 0.105 | 0.639 |
| 4.8 | 31.1 | 0.41 | 129.935 | 0.076 | 0.024 | 0.041 | 0.599 |

**Table 3: Pressure Rise (PR), Pump Speed (PS), Head Gained (HG), Time (T), Flowrate (FR) [/1000], Nanofluid Power (NFP), Brake power (BP) and Efficiency (E) obtained with 10g of Nanofluids**

| PR (bar) | PS (rev/s) | HG (m) | T (s) | FR ($m^3/s$) | NP (Kw) | BP (Kw) | E |
|---|---|---|---|---|---|---|---|
| 3.8 | 80.4 | 0.15 | 21.71 | 0.461 | 0.05 | 0.081 | 0.61 |
| 4.2 | 64.3 | 0.28 | 45.97 | 0.218 | 0.051 | 0.091 | 0.57 |
| 4.8 | 42.2 | 0.37 | 105.3 | 0.095 | 0.031 | 0.059 | 0.52 |

**Table 4: Pressure Rise (PR), Pump Speed (PS), Head Gained (HG), Time (T), Flowrate (FR) [/1000], Nanofluid Power (NFP), Brake power (BP) and Efficiency (E) obtained with 15g of Nanofluids**

| PR (bar) | PS (rev/s) | HG (m) | T (s) | FR ($m^3/s$) | NP (Kw) | BP (Kw) | E |
|---|---|---|---|---|---|---|---|
| 3.8 | 158.86 | 0.14 | 20.86 | 0.48 | 0.052 | 0.094 | 0.55 |
| 4.2 | 86.35 | 0.23 | 40.57.01 | 0.25 | 0.058 | 0.113 | 0.51 |
| 4.8 | 38.21 | 0.32 | 119.3 | 0.084 | 0.027 | 0.054 | 0.46 |

**Table 5: Pressure Rise (PR), Pump Speed (PS), Head Gained (HG), Time (T), Flowrate (FR) [/1000], Nanofluid Power (NFP), Brake power (BP) and Efficiency (E) obtained with 20g of Nanofluids**

| PR (bar) | PS (rev/s) | HG (m) | T (s) | FR ($m^3/s$) | NP (Kw) | BP (Kw) | E |
|---|---|---|---|---|---|---|---|
| 3.8 | 163.9 | 0.11 | 21.42 | 0.47 | 0.05 | 0.092 | 0.55 |
| 4.2 | 111.6 | 0.21 | 29.68 | 0.34 | 0.08 | 0.153 | 0.52 |
| 4.8 | 52.28 | 0.29 | 82.84 | 0.12 | 0.039 | 0.085 | 0.46 |

### 3.1.1 Pump Performance Characteristic Curves

The pump performance characteristic curves were obtained by plotting the head gained against the flow rate. The power and efficiencies were also plotted against the flow rate.

From the graphs of Figure 5, the actual head attained without any nanoparticle addition can be observed from the plot of head gained against flow rate. Higher head is attained at lower flow rate. The power initially rises then gradually drops while the efficiency remains linear. This indicates the actual pump performance.

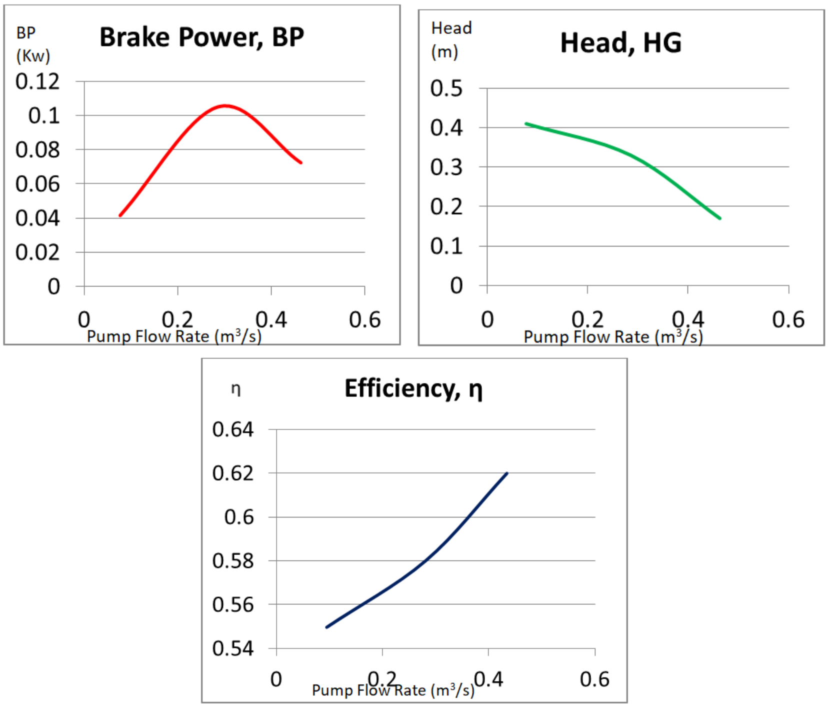


**Fig 5: Performance Characteristic Curve obtained by pumping 20Litres of water without nanoparticles**

From the graph of Figure 6, it can be deduced that with the addition of 5g of copper nanoparticles to water, the head attained is higher at lower flow rate. The power is lower as compared to those obtained for ordinary water, indicating less work done. It initially rises then gradually drops while the efficiency remains linear. This indicates a higher pump performance as compared with that without copper nanoparticles i.e. pure water.

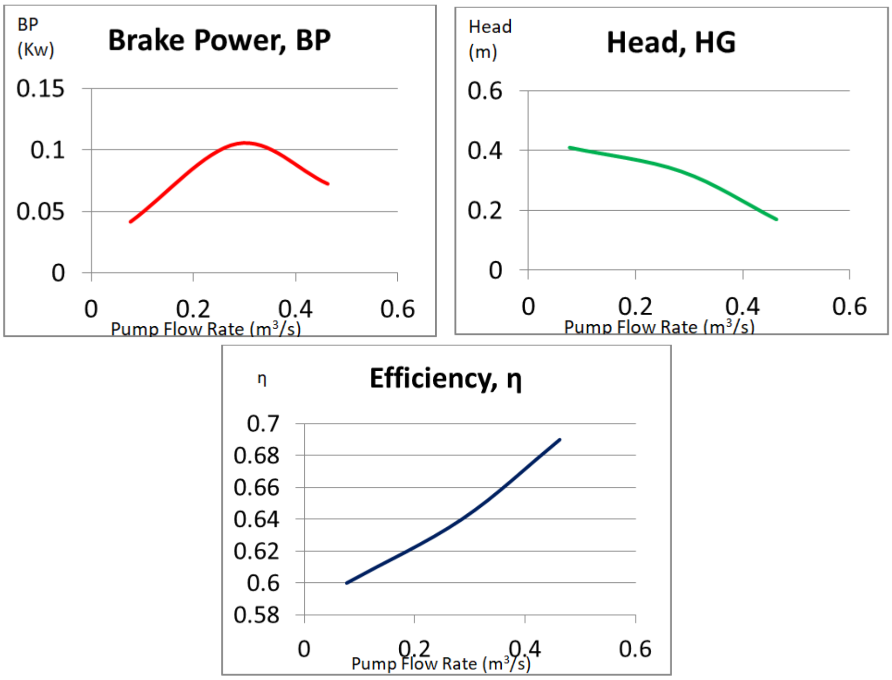


**Fig 6: Performance Characteristic Curve obtained by pumping 20Litres of water with 5g of copper nanoparticles**

From the graph of Figure 7, it can be deduced that with the addition of 10g of copper nanoparticles to water, the head attained gradually reduces as compared to when 5g was added. The power initially rises then steep gradually while the efficiency remains linear. The efficiency is lower when compared with figure 5, but with higher power. This indicates that more power is expended by the pump by doing same work of pumping 20 litres of nanofluid as compared with the addition of 5g of copper nanoparticles.

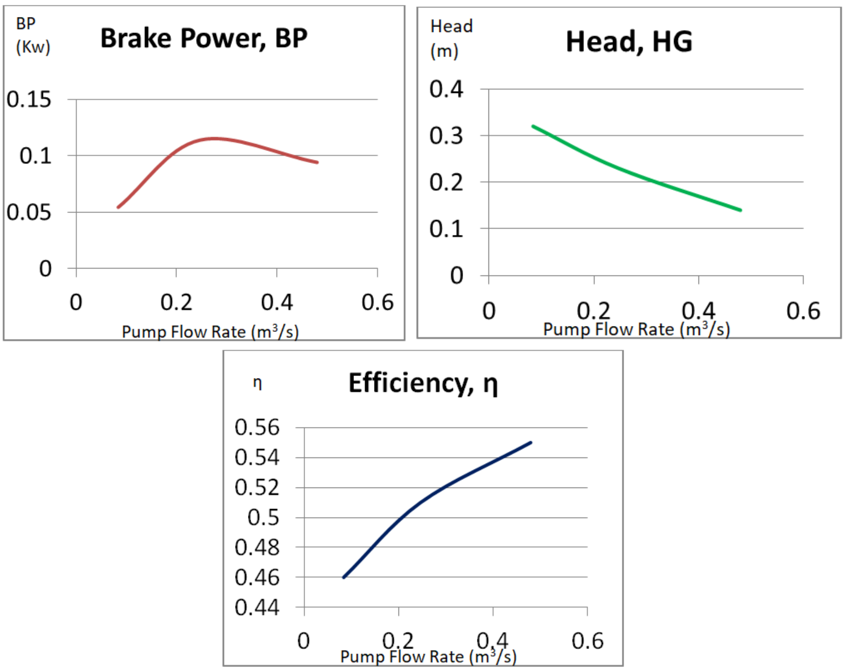


**Fig 7: Performance Characteristic Curve obtained by pumping 20 Litres of water with 10g of copper nanoparticles**

From the graph of Figure 8, it can be deduced that with the addition of 15g of copper nanoparticles to water, the head attained gradually reduces as compared to when 5g was added. The power initially rises then drop gradually while the efficiency remains linear. This is lower when actually compared with figure 5 but with higher power. This indicates that more power is expended by the pump by doing same work as compared with the addition of 5g of copper.

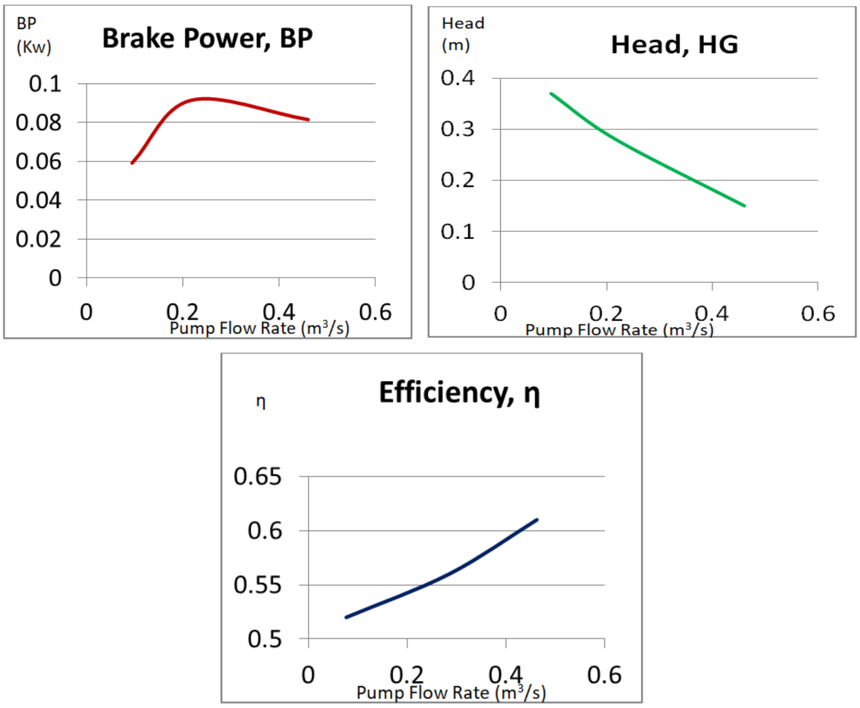


**Figure 8: Performance Characteristic Curve obtained by pumping 20 Litres of water with 15g of copper nanoparticles**

From the graph of Figure 9, it can be deduced that with the addition of 20g of copper nanoparticles to water, the head attained gradually reduces as compared to when 5g was added. The power initially rises then peak and drop steadily while the efficiency remains linear. This is lower when actually compared with Figure 5, but with higher power. This indicates that more power is expended by the pump while doing same work as compared with the addition of 5g of copper nanoparticles.

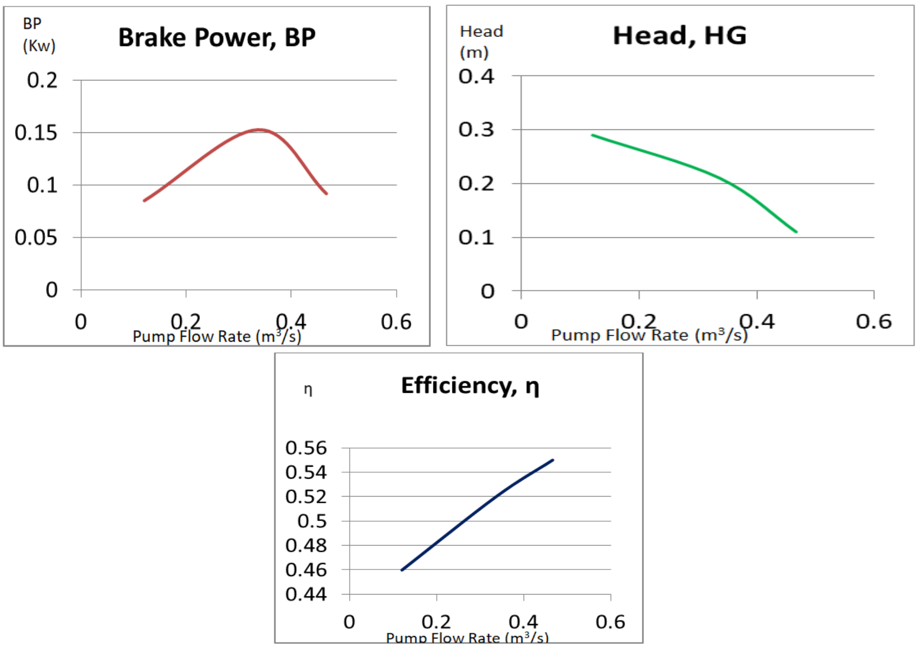


**Figure 9: Performance Characteristic Curve obtained by pumping 20Litres of water with 20g of copper nanoparticles**

At the end of the research, the following observations were made:

1. Copper nanoparticles do not readily mix with water. It forms a coagulation which is then separated with the aid of a magnetic stirrer.
2. There was an observed rapid increase in system temperature due to pumping of the nanofluid, leading to the fluid getting hot.
3. The head gained increases with an increase in pumping pressure.
4. The flowrate decreases as higher head.
5. The Pumping Power decreases with the flowrate.
6. There is a reduction in the pumping power as compared to pure liquids, without nanofluid, to achieve equivalent heat transfer intensification.
7. The Pump efficiency also decreases with the flowrate.
8. The head attained reduces as the nanoparticles concentration increases.
9. The computed pump speed or work due to vibration increases as the nanofluid concentration increases.
10. From the tables and charts, it can be deduced that the performance of the pump increases as little nanoparticles are added, i.e. 5g, then reduces with an increase in the nanoparticles concentration.

## 4. CONCLUSION

The relevance of the developed nanofluid pump test machine in the evaluation of the performance characterization of a one horse power (1HP) centrifugal pump using copper nanoparticles mixed with water to form a copper nanofluid was established.

Similarly, the effect of copper nanofluid, on the pumping power, flow rate, head gained, pump vibration, pump speed, and pump efficiency was determined. The performance characteristic curve obtained for water when compared to those obtained for copper nanofluids, revealed that there was an increased in pump efficiency at lower concentration of the copper nanofluid. There was a reduction in the pumping power as compared to pure liquids, without nanofluids.

Lastly, the relevance of the distinct properties of nanofluids to exhibit enhanced thermal conductivity and convective heat transfer coefficient compared to the base fluid was established.

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