Factors Affecting the Characteristics of Gear Pump

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Abstract- This study demonstrates the characteristics of gear pump; it helps to understand the gear pump performance. The effects of parameters (discharge pressure, suction pressure, rotation speed and temperature) on pump performance are considered separately.

When the pump is operating at constant suction pressure, pump speed and temperature, flow rate is decreased with increasing differential pressure across the pump, and it leads to a decrease in volumetric efficiency, but the mechanical power increases. Mechanical and volumetric efficiency limit the overall efficiency.

When the pump is operating at constant discharge pressure, pump speed and temperature, flow rate is affected by slip at high suction pressure but in low suction pressure flow rate is affected by slip and cavitation inception. Maximum overall efficiency is obtained at suction pressure before cavitation inception.

The pump has best volumetric efficiency at high speed rotation but mechanical efficiency is reduced in high speed, Maximum overall efficiency is in the mid-range of pressure rise. The volumetric efficiency and power consumption decrease as the oil temperature increases.

Keywords: gear pump, performance of positive displacement pumps, oil temperature, oil viscosity, suction and delivery pressure of gear pump effects.

Nomenclature

Symbols	definition	unit
C	distance between two gear rotation axis	cm
D	gear outside diameter	cm
g	gravitational acceleration	m/s^2
HM	Mono-grade oil	
ISO	International standard organization	
N	Pump rotational speed	rpm
Nd	Dynamometer speed	rpm
Pd	Discharge pressure	Bar
Pi	Mechanical power	Watt
Po	hydraulic power	Watt
Ps	Suction pressure	Bar
q	Displacement	cm3/revolution
Q	Flow rate	ℓit/min
Q_{th}	Theoretical flow rate of pump	lit/min
T	Torque	N.m
VI	Viscosity index	
W	Gear face width	cm
Δp	differential pressure	Bar
T_{oil}	oil temperature	ºC

Greek Letters

η_o	Overall efficiency	
η_m	Mechanical efficiency	
η_v	Volumetric efficiency	
ρ	Density of oil	kg/m3
Ω	Rotation speed	rad /sec
Ωs	Specific speed	

1- Introduction

Gear pumps are among the oldest and most commonly used pumps within the industry. Though the gear pump is extremely simple in its operating principle, the fundamental understanding of the instantaneous pump flow has been a subject of considerable interest for many years. Within external gear pump designs.

Michael Anderson Fish [1] worked on the gear transmission in well rig and gear pump for driving the rig motor and he studied the change in gear characteristics according to the time of operations .

Zloto et al [2] used computer and sensors for The basic characteristic parameters of the pump operation. The parameters are monitored by a computer-based measuring system at a hydraulic stand are speed, flow rate, and pressure. The structure of the measuring system and the construction of the measuring converters applied in the system are described.

Research pertaining to the theoretical flow ripple of an external gear pump is studied for pumps by Kasaragadda and Marning [3] of similar size using different numbers of teeth on the driving and driven gears. In this work, the flow ripple equation is derived based upon the flow of incompressible fluid across the changing boundaries of a control volume. From this method, it is shown that the instantaneous length of action within the gear mesh determines the instantaneous flow ripple.

The results of this study show that the driving gear dictates the flow ripple characteristics of the pump while the driven gear dictates the pump size.

As a result, it may be advantageous to design an external gear pump with a large number of teeth on the driving gear and a fewer number of teeth on the driven gear. This design configuration will tend to reduce both the physical pump size (without reducing the volumetric displacement of the pump) and the amplitude of the flow pulsation, while increasing the natural harmonic frequencies of the machine [3].

He Jianing et al [4] worked on new type of hydraulic pump the involutes circular arc gear pump. The Involutes circular arc gear pump has all advantages of the traditional involutes gear pump, while its mechanical performance is better than the traditional involutes gear pumps. The new pump is especially suitable for the high pressure and high flow rate situation.

Alibert et al[5] studied the influence of hydraulic fluid viscosity on pump efficiency for vane, gear and piston pumps, and will highlight the impact of viscosity index and shear stability. The analysis of the data demonstrates that a properly selected hydraulic fluid significantly improves overall efficiency, the selection of an appropriate high-VI (viscosity index), highly shear stable oil, can improve pump efficiency by at least five percent compared to a conventional HM (mono-grade) fluid of the same ISO grade. Chen liping et al [6] studied modeling and simulation of gear pumps based on Modelica/Mworks and they found the from the pressure distribution in the space of a gear tooth, radial force on shaft can be easily calculated, on which the motion of the shaft can be simulated based. C. Raghunathan et al [7] studied analysis mechanical behavior of hydrodynamic gear pump using Taghushi and response surface method (RSM) and they showed that the response surface methodology analysis shows appreciable can increase in respect of performances in mass rate, face rate, speed and loading against the Taghushi sort of experiment results. Svishchev A. V, Aistove [8] studied the theoretical and experimental studies comparison of the pressure pulsation in the discharge chamber of the gear pump, they showed that the difference in the pressure fluctuation amplitude values in the discharge chamber of the NSh-32K gear pump does not exceed 14%. Leonid et al [9] studied the exploration of acoustic characteristics of gear pumps with polymeric pinion shafts and the conducted experiment shows that acoustic characteristics of the pump unit depend on different material drive and driven rotor, the dedicated that replacing metal pinion shafts to polymer reduce pump unit noise on the test modes.

2- Theoretical approach

The theoretical part deals with the theoretical basis of the gear pump. First, theoretical method for calculating displacement of pump then calculating volumetric efficiency, mechanical power relation is mentioned and factors which lead to change in overall efficiency are studied.

2-1- Theoretical displacement of gear pump

The displacement of a pump is the volume of liquid moved in those pockets between gear teeth. It is the theoretical output of the pump before any losses are subtracted. The instantaneous mode of displacement varies slightly as the teeth move through different positions in the mesh, so displacement per shaft revolution cannot be calculated exactly.

An estimation of the displacement of an external gear pump can be made using the following formula [10] :

$$q = \frac{\pi}{2} * (D_a^2 - C^2) * W \quad \text{cm}^3/\text{rev} \qquad (1)$$

This formula assumes that both gears have the same outside diameter and number of teeth. The addendum of gears for pumps is often extended when compared to power transmission gears[5].

Theoretical capacity can be determined by following formula:

$Q_{th}= q * N / 1000$ (liter/minute) (2)

2-2 Volumetric efficiency

It is defined as the ratio of actual flow rate to the theoretical flow rate[5].

The constant theoretical displacement is straight horizontal line. The actual capacity flow rate reduces with the pump head because of 'slip'. It is proportional to the head of pump (discharge head minus suction head). When head approach to zero, the capacity is equivalent to the theoretical displacement. Therefore the actual discharge is the difference between theoretical discharge to internal leakage of the pump [11].

Volumetric efficiency=actual capacity/theoretical capacity

$\eta_v = Q/Q_{th}$ (3)

Actual capacity=theoretical capacity – internal leakage

2-3 Hydraulic power and efficiency

The hydraulic power (P_o) produced by pump is equal to the product of actual flow rate of the pump and pressure drop across the pump[5]:

$P_o=\Delta P*Q/0.6$ (4)

$\Delta P= p_d - p_s$ (5)

And overall efficiency is equal to the ratio of hydraulic power produced by pump (P_o) to the actual total power provided to the pump (P_i) .

$\eta_o =P_o/P_i$ (6)

the power required to rotate a pump is the multiplication of torque(T) in (Nm) to rotating speed (N in rpm) [1].

$Pi= 2*\pi*N*T/60$ (7)

And overall efficiency is a product of mechanical efficiency to volumetric efficiency [5]

$\eta_o = \eta_m * \eta_v$ (8)

in simple terms, the overall efficiency of pump is a measure of ability to transform mechanical energy in to hydraulic energy.

The performance of hydraulic pumps is a critical factor in overall hydraulic system reliability. There are two elements of hydraulic efficiency: volumetric efficiency and hydro mechanical efficiency.

3- Experimental Work

The experiments were done by MERLIN4 gear pump module and the test rig is consisting of three component:

1- MERLIN 4 gear pump Fig. 1.

2- MERLIN MASTER 2000 Dynamometer Fig. 2.

3-Computer for data proceeding and reading.

Main parts of MERLIN4 gear pump are;

- Gear pump
- An oil reservoir
- Inlet and outlet valves
- A pressure relief valve (integrated with gear pump).
- Oval gear flow meter
- Mechanical pressure gauges
- Electronic pressure transducers

The gear pump draws oil from reservoir. The oil flows around a circuit, incorporating the valves, gauges and flow meter, and eventually returns to the reservoir. The two different types of pressure measurement instrument allow the user to make a comparison between the analogue instruments and analogue electronic transducers. The marline 4 Gear pump is double helical gear machine which will run on wide range of oils. It produces a smooth non-pulsating flow. The double helical rotor eliminates end thrust. The pump itself is self priming and has a built in by-pass type pressure relief valve to protect the pump from damage if the outlet becomes blocked or accidentally closed. The oil temperature is measured by thermocouple and indicated by one of the displays on master 2000 controller [12].

4- Results and discussion

Calculations are performed to the measured data, then relation between change in factors effecting on the characteristic of pump like discharge pressure, suction pressure, pump speed, flow rate, mechanical input power, volumetric efficiency, and overall efficiency are drawn, Behavior of gear pump is discussed according to above factors mentioned.

4.1 Effect of pressure difference and temperature rise on gear pump performance:

1- The flow rate of oil discharged by gear pump decreases by increasing pressure difference across the pump because of increasing internal leakage of pump's 'slip' as shown in Fig. 3.

1- In Fig. 4., the power required to rotate the pump at speed (450 rpm) increases with increasing of pressure difference according to equation 4. Power required to rotate a pump decreased with temperature rise, because of viscosity decrease, it results in decreasing mechanical losses, when the pump operated at situation where rotation speed (450rpm) and suction pressure are constant with variable discharge pressure.

2- In Fig. 5 the volumetric efficiency decreases as the pressure difference across the pump increases and this can be returned to the leakage inside the pump. And the volumetric efficiency decreases as the temperature increases due to the internal slip increase.

3- In fig. 6 displays the effect of pressure difference on the pump efficiency at different speeds. The pump has maximum volumetric efficiency at low pressure difference across the pump and slip increases with increasing the pressure difference. Maximum efficiency is obtained at speed 450 rpm at pressure difference of 4.5 bar, but for speed 900 rpm at pressure difference 6.6 bar.

4.2 Effect of suction pressure and temperature rise on gear pump performance:

1- Fig. 7 shows that, pump flow rate decreases when suction pressure decreases, the effect is small at the beginning of this decrease in flow rate, it starts slipping until reaches -0.5 bar, then the curve begins to decrease rapidly to participate the action of cavitations in oil where bubbles begin to appear this noticed at flow meter window and noise is heard. The flow rate is less in case of 45ºC temperature than 35ºC temperature because of internal slip increase.

2- Fig. 8 shows that the overall efficiency and the volumetric efficiency decrease as the suction pressure decreases and this may be returned to the inception of cavitation as the suction pressures reduces. Overall efficiency is higher in 45ºC than that at 35ºC as the friction losses reduces due to low viscosity at higher temperatures.

3- In Fig. 9 the power consumption increases as the suction pressure decreases and this can returned to increase of pressure difference. At higher temperature the power required to pump the oil is less than that at low temperatures as the density and viscosity decrease.

4.3 Effect of pump speed and temperature on gear pump performance:

Fig. 10 shows the relation between flow rates and pump speed at situation where pressure difference across the pump is constant, flow rate increases by increasing pump speed because of increasing number of displacements. The flow rate is less in high temperature than that of low temperature because of internal leakage.

5-Conclussions

The following conclusions are obtained in this study:

1- Flow rate and volumetric efficiency decrease as discharge pressure increases at constant suction pressure. Power input increases as the discharge pressure rises. Maximum overall efficiency is in the mid-range of pressure rise.

2- Flow rate and volumetric efficiency decrease as the suction pressure decreases. Decrease in flow rate for suction pressure from (0 to -0.5) bar takes place by slip, but for suction pressure from (-0.5 to -0.9) takes place due to slip and cavitation inception.

3- Flow rate and volumetric efficiency increase as rotation speed increases, while slip decreases with increase in pump speed. Overall efficiency is almost constant at different operating speeds.

4- Oil viscosity and oil density decreases with temperature rise, this leads to decrease in flow rate, decrease in mechanical input, decrease in volumetric efficiency

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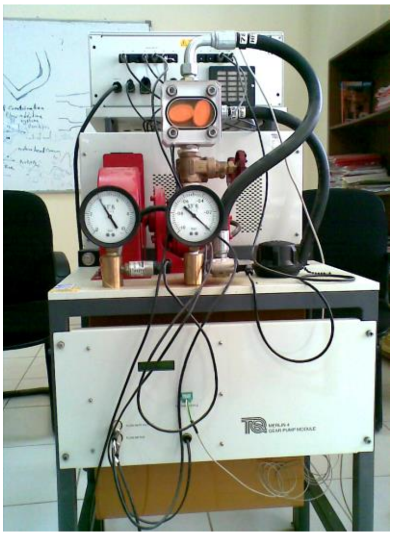

Fig. 1 MERLINE 4 Gear Pump Module

Fig. 2 MERLINE MASTER 2000 Dynamometer

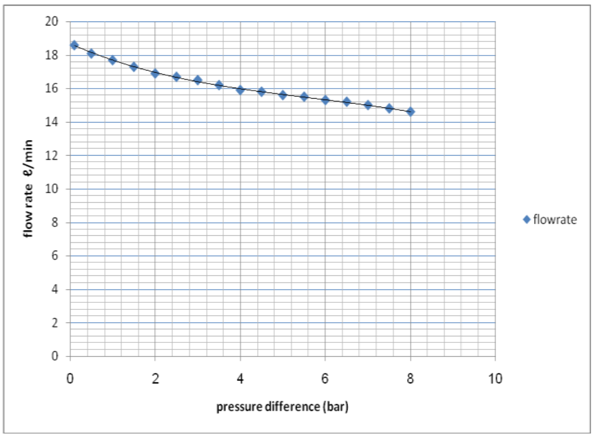

Fig. 3. Effect of pressure difference on flow rate

(N= 900 rmp, oil temp. = 35°C)

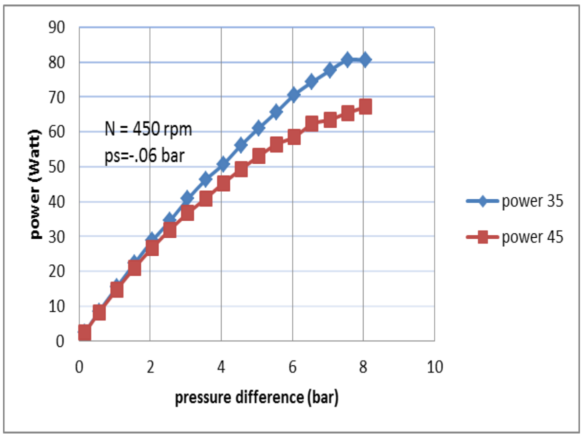

Fig. 4. Effect of pressure difference on power

(N= 450 RPM, oil temperature 35°C & 45°C)

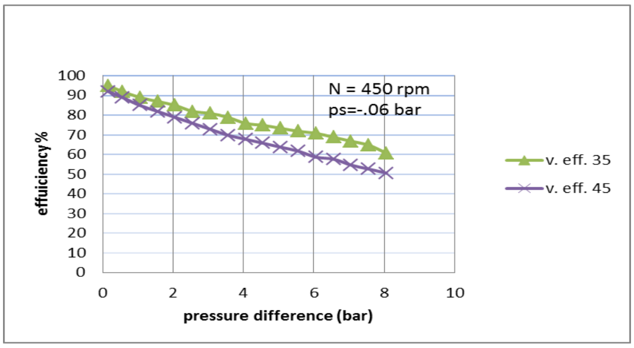

Fig. 5. Effect of pressure difference on volumetric efficiency at different oil temperatures

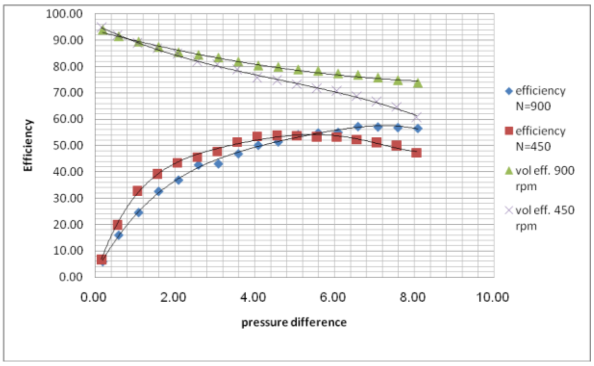

Fig. 6. Effect of pressure difference on volumetric and overall efficiency in different speeds, (35 °C)

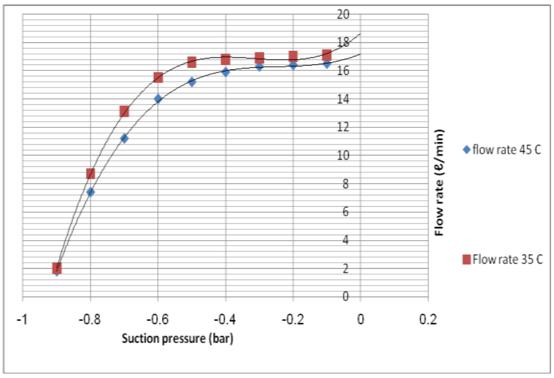

Fig. 7. Effect of suction pressure on flow rate

(N= 900 rpm, P_d=2 bar, Temp. 35°C and 45°C)

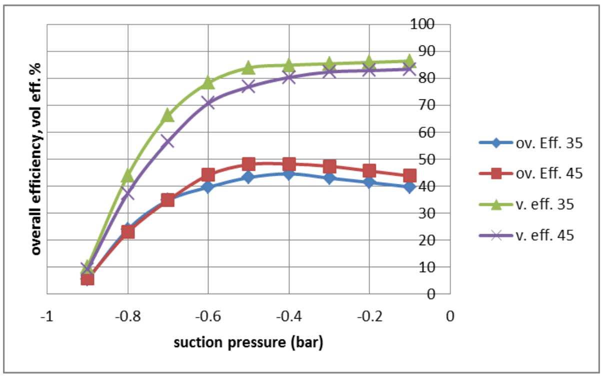

Fig. 8 Effect of suction pressure on volumetric and overall efficiency at different temperatures (35°C and 45 °C, and speed = 450 rpm.)

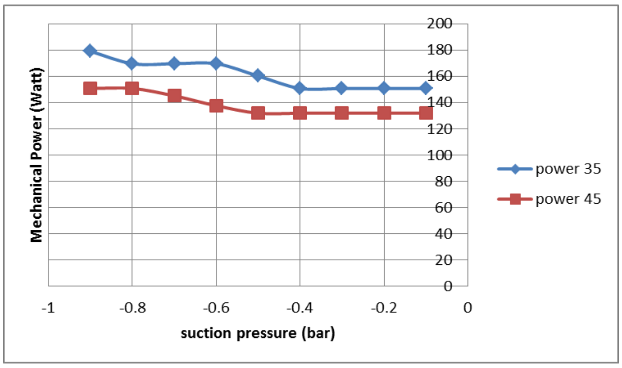

Fig. 9 Effect of suction pressure on mechanical power, at different temperatures(35ºC and 45 ºC, N = 450 rpm)

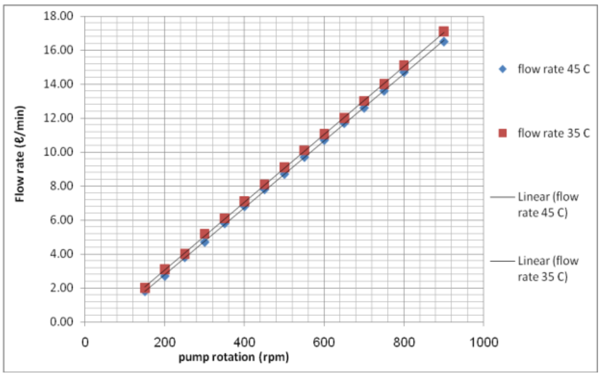

Fig. 10 effect of speed on flow rate (Pd = 2 bar, Ps=0.06bar, at different temperatures 35ºC and 45 ºC)