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Review Article

Application of Nanomaterials for Improving the Tribological Performance of Oil and Gas Equipment

Gulnar A. Hamidova

Department of Mechanics and Mathematics, School of Advanced Technologies and Innovation Engineering, Western Caspian University, 17 A, Ahmad Rajabli Street, III Parallel, AZ1072 Baku, Azerbaijan

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Abstract

Oil and gas equipment, during its operational lifespan, encounters a multitude of natural and technological influences, which subsequently alter its functional capabilities, thereby precipitating defects and failures. A principal contributor to the malfunctioning of the working surfaces within wellhead components, such as Christmas tree assemblies and gate valves, is wear, which is generated by elevated pressure and friction. Understanding wear's properties and working principles is vital for improving equipment reliability, extending its lifespan, and increasing operational efficiency. Recently, using nanoparticles has been a key area of research for improving tribological processes. Nanoparticle-based lubricant additives, nano-scale ceramic reinforcements, and high-hardness nanocomposite coatings like TiN, CrN, DLC, and AlTiN, reduce energy losses caused by friction, minimize micro-wear on contact surfaces, and improve mechanical durability. These nanotechnology solutions significantly enhance the tribological performance of contact zones in wellhead equipment, which leads to a longer operational lifespan. Studies exhibit that machinery with nanostructured surface coatings experiences less wear over time and maintains consistent mechanical properties, even when subjected to pressures as high as 105 MPa. The use of these nanostructured coatings helps to reduce early defects, improve the control of friction-related factors, and notably lower the chance of equipment failure.

Keywords: christmas tree assembly, gate valve, tribological parameters, nanocomposite coatings, wear volume, wear rate

1. Introduction

Gate valves are fundamental components in the wellhead systems of industrial and oil production operations. These valves work in environments with high pressure, fast flow, turbulence, and aggressive chemicals. These harsh conditions increase frictional energy losses on the valve's working surfaces, which leads to faster wear over time [1].

This study investigates how wear rate and wear volume change over time in gate valves, which are used at pressures up to 105 MPa [2]. Gate valves work by moving a disc or wedge-shaped sealing element vertically, and they are mainly designed to be either fully open or fully closed. Although friction is low when the valve is fully open, it increases significantly when the valve is closed. This is due to the concentrated contact stress, which leads to considerable wear [3].

2. Wear Analysis of Gate Valve Components

During the design of gate valves, accurately assessing mechanical and tribological stress in friction areas is vital. At this stage, engineering solutions using nanotechnology have become increasingly relevant, including:

Nano-scale hard coatings
(diamond-like carbon (DLC), titanium nitride (TiN), chromium nitride (CrN), aluminum titanium nitride (AlTiN))

- Strong hardness and low friction
- Higher corrosion resistance
- Lower micro-wear on working surfaces

Nanocomposite reinforcements
(titanium silicon nitride (Ti–Si–N) and chromium aluminum nitride (Cr–Al–N))

- Strong resistance to impact loads
- Thermal stability at higher temperatures

Nanoparticle-enhanced lubricants
(molybdenum disulfide (MoS_2), tungsten disulfide (WS_2), graphene (C_n), titanium dioxide (TiO_2), Copper (II) oxide (CuO) nanoparticles (NPs))

- 20-40% less friction
- Lower wear rate [4].

3. Effect of Nanomaterials on Wear Reduction

These nanotechnology-based approaches significantly minimize wear, potentially extending the lifespan of equipment by 1.5 to 3 times [5].

In this research, the change in wear volume over a period of 9 years (scale factor: 1/720) and the influence of nanomaterial application on this trend were comparatively analyzed. Results indicate that surfaces modified with nanocomposite coatings demonstrate significantly lower wear compared to conventional metallic surfaces, ensuring long-term functional reliability of Christmas tree components [6].

Wear rate over a period of 1 month: $V_{y1} = \frac{0.05}{1} = 0.05$ µs (1)

Wear rate over a period of 2 months: $V_{y2} = \frac{0.2}{2} = 0.1$ µs (2)

Wear rate over a period of 3 months: $V_{y3} = \frac{0.36}{3} = 0.12$ µs (3)

Wear rate over a period of 4 months: $V_{y4} = \frac{0.6}{4} = 0.15$ µs (4)

Wear rate over a period of 5 months: $V_{y5} = \frac{0.75}{5} = 0.15$ µs (5)

Wear rate over a period of 6 months: $V_{y6} = \frac{0.72}{6} = 0.12$ µs (6)

Wear rate over a period of 7 months: $V_{y7} = \frac{0.7}{7} = 0.1$ µs (7)

Wear rate over a period of 8 months: $V_{y8} = \frac{0.64}{8} = 0.08$ µs (8)

Wear rate over a period of 9 months: $V_{y8} = \frac{0.72}{9} = 0.08$ µs (9)

The symbol “µs” means microsecond.

These results are presented in Figure 1 [7]. Also, Table 1 presents the time-dependent wear rate in conventional wells. Figure 2 presents the time-dependent wear volume in conventional wells [8].

Table 1. Time-dependent wear rate in conventional wells.

Jy (mkr)	0.05	0.2	0.36	0.6	0.75	0.72	0.7	0.64	0.72
t-(sec)	1	2	3	4	5	6	7	8	9
$V_Y(mkr/sec)$	0.05	0.1	0.12	0.15	0.15	0.12	0.1	0.08	0.08

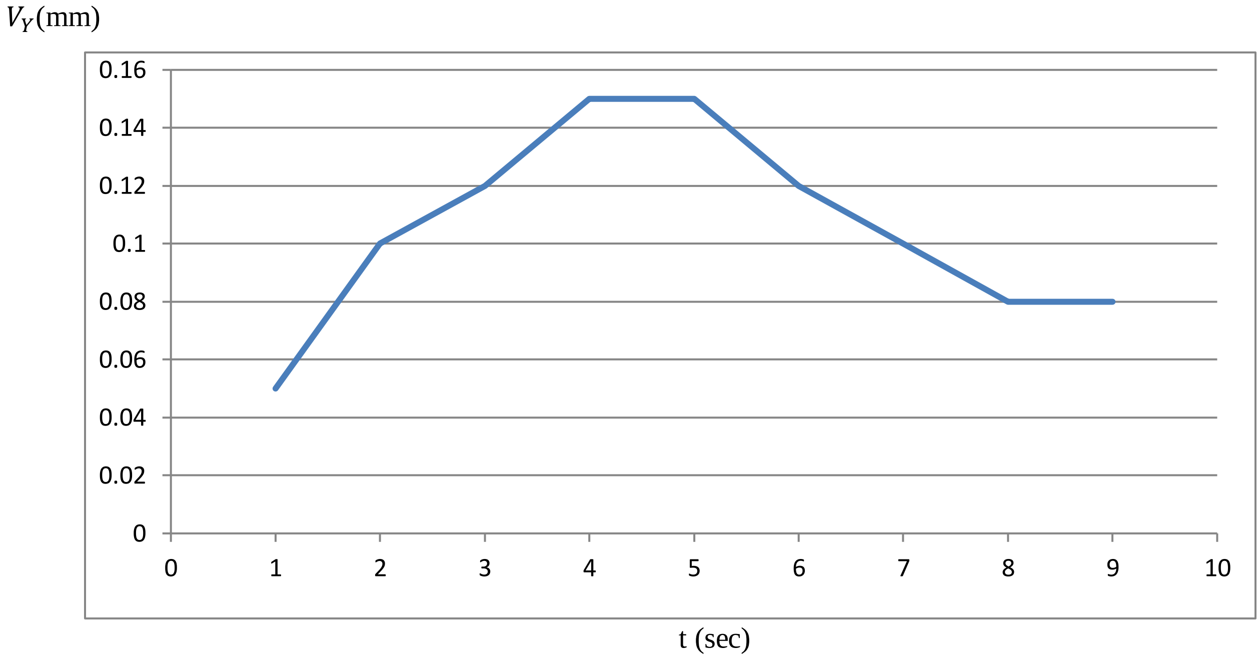

Figure 1. Time-dependent wear rate in conventional wells.

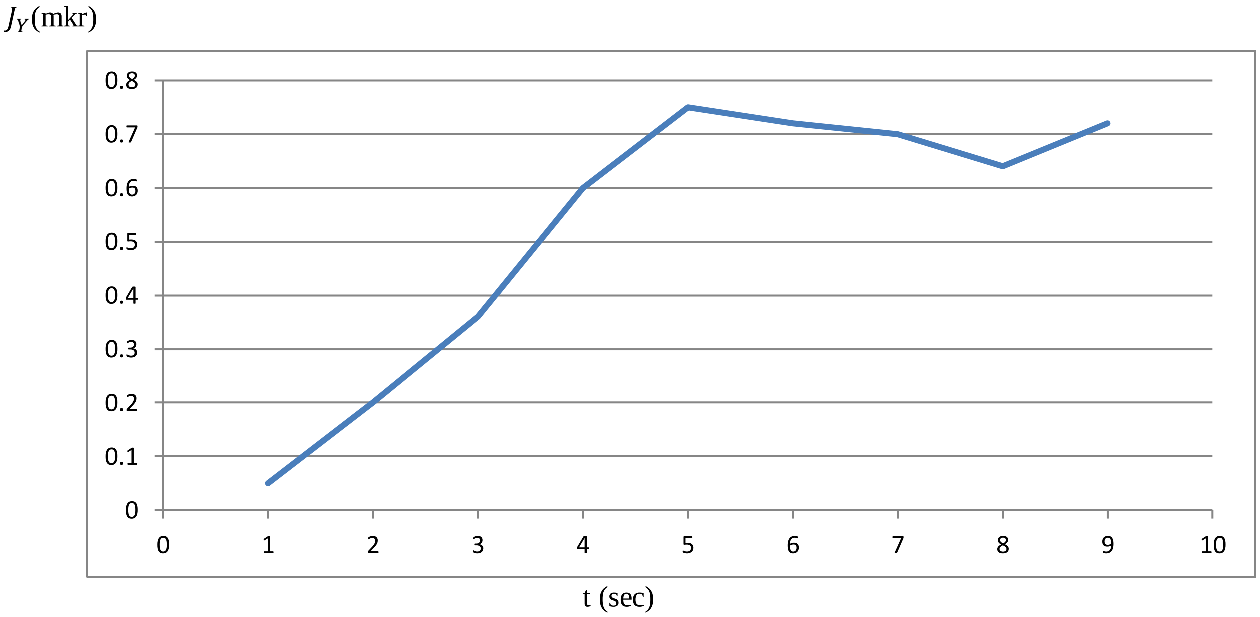

Figure 2. Time-dependent wear volume in conventional wells [8].

The wear rate in sandy wells is analyzed. Based on the wear volume, the wear rate is determined over a period of 9 months.

Wear rate over 1 month: $\mathrm{V_{y1}} = \frac{0.5}{1} = 0.5$ mkr/sec (10)

Wear rate over 2 months: $\mathrm{V_{y2}} = \frac{0.12}{2} = 0.6$ mkr/sec (11)

Wear rate over 3 months: $\mathrm{V_{y3}} = \frac{0.27}{3} = 0.9$ mkr/sec (12)

Wear rate over 4 months: $\mathrm{V_{y4}} = \frac{0.36}{4} = 0.9\ \mathrm{mkr/sec}$ (13)

Wear rate over 5 months: $\mathrm{V_{y5}} = \frac{0.3}{5} = 0.6\ \mathrm{mkr/sec}$ (14)

Wear rate over 6 months: $\mathrm{V_{y6}} = \frac{0.36}{6} = 0.6\ \mathrm{mkr/san}$ (15)

Wear rate over 7 months: $\mathrm{V_{y7}} = \frac{0.35}{7} = 0.5\ \mathrm{mkr/san}$ (16)

Wear rate over 8 months: $\mathrm{V_{y8}} = \frac{0.16}{8} = 0.2\ \mathrm{mkr/san}$ (17)

Wear rate over 9 months: $\mathrm{V_{y9}} = \frac{0.18}{9} = 0.2\ \mathrm{mkr/san}$ (18)

The obtained results are presented in Figure 3. Table 2 presents the time-dependent wear rate in sandy wells.

Table 2. Time-dependent wear rate in sandy wells [9].

$V_Y(\frac{mkr}{sec})$	0.5	0.6	0.9	0.9	0.6	0.6	0.5	0.2	0.2
t-(sec)	1	2	3	4	5	6	7	8	9
$\mathrm{J_y}$ (mkr)	0.5	0.12	0.27	0.36	0.3	0.36	0.35	0.16	0.18

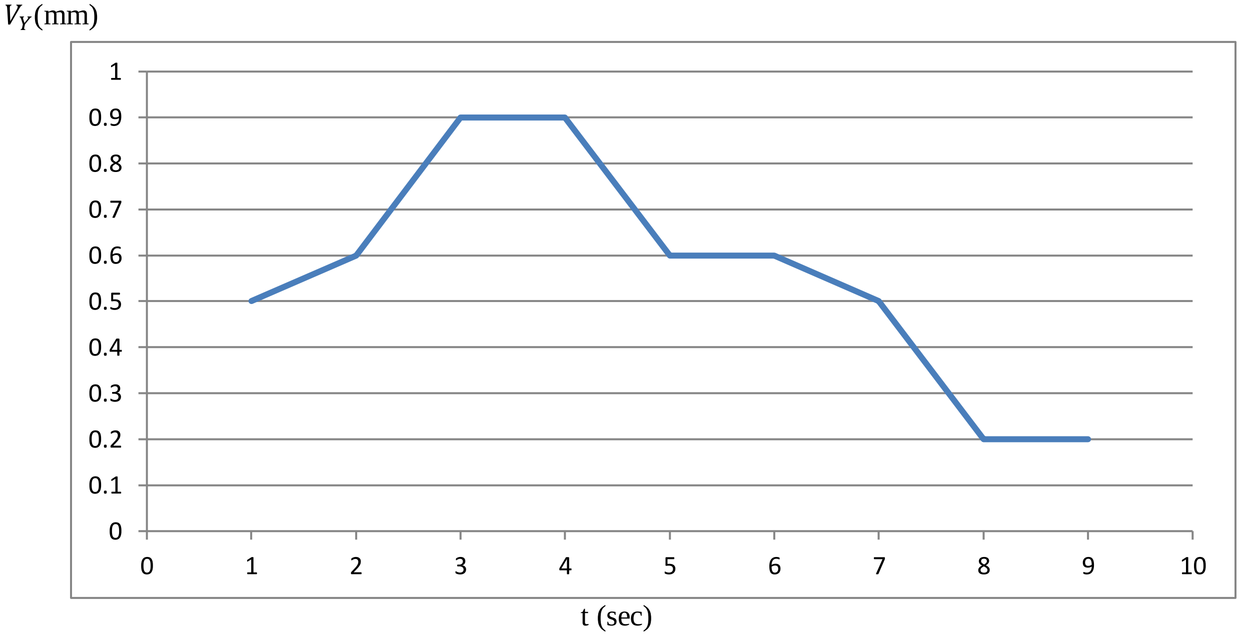

Figure 3. Time-dependent wear rate in sandy wells.

4. Conclusion

Under specific friction conditions, a material's resistance to wear is characterized by its wear resistance. Wear resistance is expressed as the inverse of the wear rate or wear volume and serves as a key parameter in evaluating tribological processes. An increase in temperature within the friction zone leads to changes in the physical and mechanical properties of the surface layers, resulting in structural weakening and, consequently, an increase in the wear rate.

The conducted studies indicate that, under various operating conditions and different friction pairs, similar types of micro-roughness form on the surface immediately after initial material processing. This demonstrates that, in the initial stage of the wear process, tribological behavior exhibits a certain degree of universal characteristics.

Author Contributions

The author confirms responsibility for the conception and final approval of the manuscript.

Conflict of Interest

The author declares no competing interests.

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Abbreviations

Diamond-like Carbon (DLC), Titanium Nitride (TiN), Chromium Nitride (CrN), Aluminum Titanium Nitride (AlTiN), Titanium Silicon Nitride (Ti–Si–N), Chromium Aluminum Nitride (Cr–Al–N), Molybdenum Disulfide (MoS_2), Tungsten Disulfide (WS_2), Graphene (C_n), Titanium Dioxide (TiO_2), Copper (II) Oxide (CuO), Nanoparticles (NPs).

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