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# Experimental study on frictional characteristics of tungsten carbide versus carbon as mechanical seals under dry and eco-friendly lubrications

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ABSTRACT

Lubrication reduces the friction between the interfaces of sliding surfaces in the mechanical seals that operate for extended period of time. Due to environmental issues caused by mineral oil-based lubricants, the use of organic based vegetable oils had increased worldwide due to the nontoxic and biodegradable characteristics. In this work an experimental study was carried out by employing a seal pair of tungsten carbide and resin impregnated carbon mechanical seals, its frictional behaviour was studied under the eco-friendly lubricant from the class of vegetable oils — soybean oil and canola oil with an eco-friendly solid lubricant i.e. boric acid powder. An experimental setup was designed and fabricated to study the frictional characteristics of the seal for varying normal load and constant speed. The friction characteristics was studied under unlubricated conditions, independent paraffin oil, soybean oil, canola oil lubricating modes and finally 1 wt.%, 3 wt.% and 5 wt.% of boric acid powder mixed individually with soybean and canola oil. After all running-in test of all lubricating conditions, 5 wt.% of boric acid powder mixed with soybean oil had contributed a hybrid tribofilm and resulted in the lowest friction coefficient value in the range of 0.06–0.07.



## 1. Introduction

Biodegradable, bio-based, eco-friendly, renewable, non-toxic, and green were the recent powerful words echoing throughout the industry [1]. In particular to the lubricants, the industrial sector had been quietly looking into biodegradable, eco-friendly and non-toxic fluids in all engineering system without replenishment. Increased concerns about environmental damage caused by mineral oil based lubricants had created a growing worldwide trend of promoting vegetable oil as base oil for engineering lubricants [2]. To initiate and boost the use of biodegradable and eco-friendly products, government incentives and mandatory regulations were needed to put pressure on the industries that release toxic lubricants into the environment [1,3]. The bureau of Indian standards had issued a certification mark named “Eco-mark”, in a motive to increase awareness among consumers to use eco-friendly and among producers to produce products that had minimum environmental impact [4]. These eco labelling schemes include ecological test requirements, prohibitions and manufacturer's declarations which often differ and were being continually updated [5,6].

Mechanical seal is a device that helps in joining systems or mechanism together preventing leakage, containing pressure, and excluding contamination [7,8]. The industrial applications of mechanical seal were innumerable such as for pumps, mixers, dryers and other specific equipment, commonly used anywhere, in which liquid and gases were transferred by rotating equipment [9]. Usually mechanical face seals were composed of two mainly flat rings, a stationary ring (harder material) and a rotating ring (softer ring) which was in relative motion, separating a pressurized fluid from the atmosphere, with a compression spring and a drive mechanism [10]. The stationary ring was considered as one of the important components which influence the frictional properties and hereby deciding the life span of mechanical seals. The most commonly employed materials for stationary ring of mechanical seal were ceramics such as silicon carbide (SiC), silicon nitride ($Si_3N_4$), tungsten carbide (WC) [11], aluminium oxide ($Al_2O_3$) and many other tailored alloys were being tested as a future material [12–14]. In the application of mechanical seal, lubrication was one of the important factor, which plays a crucial role in improving the tribological properties and in preventing the friction and wear related problems. In the absence of adequate lubrication, sliding between mating surfaces in extended operations will result in high levels of friction, wear and ultimately results in the failure of the materials in contact. These high frictional values were primarily caused by the inherent roughness of the materials in contact and the large pressures that developed between them. To reduce the undesirable effects of wear, lubricants were generally applied along the interface of contacting materials. The load rather than being carried

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by individual asperities, lubricant films separate asperity interaction and allow contact pressures to be more evenly distributed over the contact interface. The conventionally used lubricants for the application of mechanical seals were water, ethylene glycol/water (50/50 mixture), propylene glycol/water (50/50 mixture), propanol, diesel, and various tailored synthetic oils considering the loading and running conditions.

Upon the detailed literature study, as far our knowledge is concern, there was not enough study showing the frictional behaviour of mechanical seal under the eco-friendly lubrication modes. So in this present work, an attempt was made to study the frictional performance of mechanical seal involving an effective pair of tungsten carbide (stationary seal) and resin impregnated carbon (rotating ring) under eco-friendly lubrications. Vegetable oils were being considered as the potential source of environmentally friendly lubricants and they primarily consist of triglycerides [5,15], which were the glycerol molecules with three long chain fatty acids attached at the hydroxyl groups via ester linkages. This triglyceride structure provides desirable qualities for boundary lubrication. It was due to their long and polar fatty acid chains, which provide high strength lubricant films that interact strongly with metallic surfaces, reducing both friction and wear [4,5]. The polarity of fatty acids produces oriented molecular films, which provides oiliness and imparts antifriction properties. Fatty acids were thus believed to be key substances with regard to lubricity [16]. The most commonly used vegetable oils were castor oil, canola oil, palm-oleic oil, soybean oil, pongamia–pinnata oil, olive oil, neem oil and coconut oil [17,18]. Another category, which was found to significantly reduce friction and wear during sliding contacts, was solid lubricants. Most of these lubricants [19], which include graphite, molybdenum disulphide, tungsten disulphide and calcium fluoride [20], belong to a specialized class of materials known as lamellar solids, boric acid was another often overlooked lamellar solid that was found to be an effective lubricant [21]. Two of the most important characteristics of boric acid in using as a lubricant were readily available and environmentally safe. Because of boric acid's lamellar structure, it was concluded that it had self-lubrication properties like $MoS_2$ and graphite and that they can be used in practice as solid lubricants. Erdemir [22] stated that boric acid as an additive had better lubrication properties than $MoS_2$ in humid conditions. In its solid form (boric acid), a weak acidic white powder that was soluble in water (about 27% by weight in boiling water and about 6% at room temperature), soft, ductile, stable, free flowing and can be easily handled exhibits good lubricious properties and can be readily mixed with many oils in reducing the friction between the mating surfaces [23]. It was very inexpensive, as finely ground technical grade boric acid powder (>99% pure) was commercially available for less than INR 50/kg.

In this present work, an eco-friendly lubricant consisting of soybean oil and canola oil mixed individually with varying weight proportions of 1%, 3% and 5% of boric acid powder was tested with the mechanical seal involving tungsten carbide (stationary ring) against resin impregnated carbon (rotating ring). Also the seal pair was tested under the paraffin oil lubrication, in a motive to evaluate and compare with the conventional base oil, which has been traditionally used for mechanical seal applications. The frictional behaviour of the mechanical seals was investigated under dry, paraffin oil, canola oil, soybean oil and boric acid powder mixed individually with soybean and canola oils at various normal loads up to 500 N for a constant speed of 1500 rpm. The reason behind the testing of mechanical seal for various normal loading conditions was that for some specific seal applications like agitators and boiler feed pumps, an abrupt change in load occurs at working condition, resulting in abnormal friction and unexpected wear [24]. Also a special experimental test rig was designed and fabricated with the real-time running-in features of mechanical seal comprising of all real-time physical features, thus the real-time frictional behaviour can be obtained.

## 2. Experimental method

### *2.1. Seal and lubricant preparation*

Tungsten carbide, a most commonly employed seal face material, known for its high hardness and high strength was selected as the stationary seal and manufactured to circular hollow ring of Ø43 × Ø33 × 8 mm (od × id × thickness) through sintering process. The sliding surfaces were diamond polished and the surface roughness was measured using a Mitutoyo SJ-410 roughness tester and found to have an initial roughness of 0.03 to 0.04 μm. Resin impregnated carbon, a widely used rotating seal face material was used as a rotating ring, because of its superior wear resistance, anti-friction properties and corrosion properties. The rotating carbon ring was purchased commercially with the dimensions of Ø45 × Ø38 mm (od × id). The stationary seal and rotating seal were shown in Fig. 1. The compiled mechanical and physical properties of the stationary and rotary seals were listed in Table 1. Eco-friendly lubricants were selected from the class of vegetable oils, canola oil extracted from the seeds of rape plant and soybean oil extracted from the seeds of soybean was used as base oil for lubricant. All the classes of oils were commercially purchased from the Scientific Lubricants Private Limited, India and their properties are given in Table 2. Eco-friendly lubricant from the class of vegetable oil was premixed with 1 wt.%, 3 wt.% and 5 wt.% of boric acid powder individually, heated to 40 °C and mixed using a magnetic stirrer for 3 h until the boric acid powder was evenly spread throughout the lubricant and becomes completely soluble. The

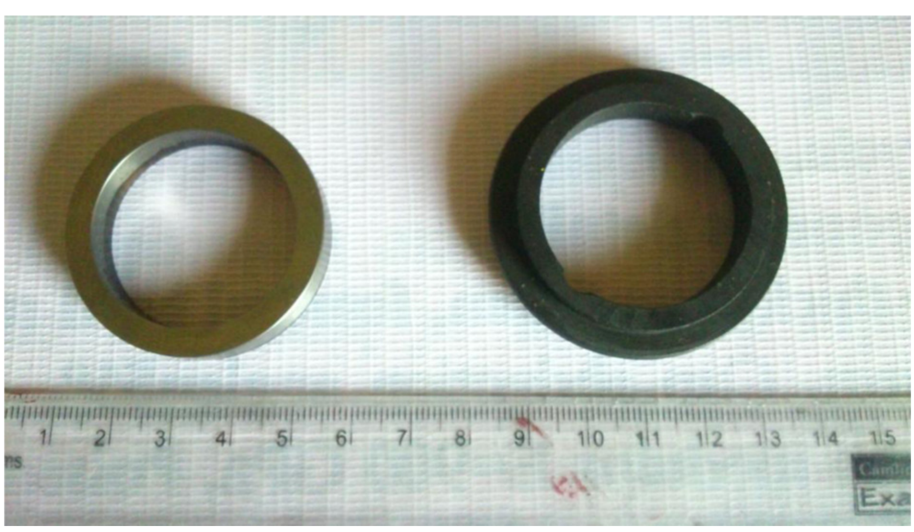

**Fig. 1.** Photography of stationary seal & rotary seal. [A] Tungsten carbide [B] Resin impregnated carbon.