Improvement of a Vertical Falling Ball Viscometer for Measuring Engine Oil Properties using 532nm diode laser, with Estimation of the Concentration of operated Oil

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Abstract

In this work, an improvement of falling ball viscometer was presented using laser beam. Several parameters such as viscosity, shear stress, shear rate, Reynolds number and drag coefficient were calculated for a sample of unused engine oil. In the other words, during the operation of engine, the variation of viscosity occurs due to the increasing in the engine temperature and may in the increasing of the concentration of engine body particles inside the oil due to friction force even with existing the oil filter there are tiny particles that pass through the oil filter, therefore a Lambert's law was used to estimate the particles concentrations of the operated oil, the resulted graphs show increasing of the impurities concentration with operation time.

Keywords: Falling Ball, Oil, Laser, Engine.

الخلاصة

تم في هذا البحث تطوير لجهاز قياس اللزوجة باستخدام حزمة الليزر لحساب عدة خواص ميكانيكية لنموذج من زيت المحركات (الغير مشغل) مثل نسبة اللزوجة، أجهاد القص، نسبة القص، عدد رينولد ومعامل السحب. الغرض من استعمال الليزر هو لحساب زمن سقوط الكرة بشكل دقيق بواسطة دائرة الكترونية للتشبيك بين مفتاح سقوط الكرة (القابض) والكاشف الليزري، أذ يبدأ حساب زمن السقوط عند فتح قابض للكرة وينتهي عند وصول الكرة لحزمة الليزر حيث تعمل الكرة على قطع الحزمة وبالتالي تقطع الأشارة الى الكاشف وبحساب زمن فتح القابض وانقطاع الاشارة يتم حساب الزمن عند أي نقطة على طول ألأنبوب الزجاجي المملوء بالزيت. ومن ناحية أخرى تم حساب نسبة التركيز لنماذج مختارة من الزيت المشغل حيث يحتوي على نسبة من الشوائب الناتجة من الأحتكاك الداخلي للمحرك وهذه الشوائب هي من الصغر حيث تنفذ من مصفاة الزيت (الفلتر) الموجودة في المحرك. أظهرت النتائج زيادة نسب التراكيز للجزيئات الممزوجة بالزيت بزيادة زمن التشغيل.

الكلمات المفتاحية: الكرة الساقطة، الزيت ، الليزر، المحرك

Introduction

The falling ball viscometer typically measures the viscosity of Newtonian liquids and gases. The method applies Newton's law of motion under force balance on a falling sphere ball when it reaches a terminal velocity (Scruby and Drain, 1990). In Newton's law of motion for a falling ball, there exist buoyancy force, weight force, and drag force, and these three forces reach a net force of zero. The drag force can be obtained from Stokes' law, which is valid in Reynolds numbers less than 1 (Zhang *et.al.*, 1990). The falling ball viscometer is well-suited for measuring the viscosity of a fluid, and the method has been stated in international standards (Costley and Shah, 1996).

Although the falling ball method has been well developed and is stated in the international standards, it is somewhat inconvenient to operate this type of viscometer. For example, it is difficult to determine where the falling ball arrives at the terminal velocity, i.e., whether the distance between the beginning record line and the starting fall position is sufficient (Singh *et.al.*, 1997 ; Drumheller and Bedford, 1994). Therefore, the purpose of this study was to develop a new method based on the laser detection system method, it will be referred as a vertical falling ball viscometer. Viscosity**,** resistance of a fluid to flow (Bruttomesso *et.al.*, 1993). This resistance acts against the motion of any solid object through the fluid and also against motion of some liquids like petrol, alcohol, water etc. flow more freely than other liquids like, honey, glycerin, oil etc. This is due to the property of the liquid called viscosityby virtue of which the liquid opposes the relative motion between its different layers. When a sphere is placed in an incompressible Newtonian fluid, it initially accelerates due to gravity. After this brief transient period, the sphere achieves a steady settling velocity (a constant terminal velocity). For the velocity to be steady (no change in linear momentum), Newton's second law requires that the three forces acting on the sphere, gravity (FG), buoyancy (FB), and fluid drag (FD) balance (Shah and Balasubramaniam, 1996; Bottinga and Richet, 1995). These forces all act vertically and are as follows:

gravity: $$F_G = -\frac{\pi}{6}\rho_p D_p^3 g \qquad (1)$$

buoyancy: $$F_B = +\frac{\pi}{6}\rho D_p^3 g \qquad (2)$$

fluid drag: $$F_D = \frac{\pi}{8}\rho V_p^2 D_p^2 C_D \qquad (3)$$

whereρp is the density of the solid sphere, ρ is the density of the fluid, Dp is the diameter of the solid sphere, g is the gravitational acceleration (9.8m/s2), Vp is the velocity of the sphere, and CD is the drag coefficient. The gravitational force is equal to the weight of the sphere (Ferguson and Kemblowski, 1991). The buoyancy force acts upwards and is equal to the weight of the displaced fluid. The drag force acts upwards and is written in terms of a dimensionless drag coefficient. The drag coefficient is a unique function of the dimensionless Reynolds number, Re.(Whorlow, 1992). The Reynolds number can be interpreted as the ratio of inertial forces to viscous forces. For a sphere settling in a viscous fluid the Reynolds number is :

$$Re = \rho V_p D_p / \mu \qquad (4)$$

where μ is the viscosity of the fluid. If the drag coefficient as a function of Reynolds number is known the terminal velocity can be calculated. For the Stokes regime, Re<1, the drag coefficient can be determined either analytical (as will be shown later in the course) or empirically (Macosko, 1994; Wakeham *et.al.*, 1991). Under these conditions CD = 24/Re and the settling velocity is :

$$V_p = g D_p^2 (\rho_p - \rho)/18\mu \qquad (5)$$

The falling ball viscometer is one of the practical applications of either Eqn.(5) or Eqn. (6). The falling ball viscometer requires the measurement of a sphere's terminal velocity, usually by measuring the time required for sphere to fall a given distance. The viscosity from either Eqn. (5) or Eqn. (6) depending on the Reynolds number (Gui and Irvine,1994 ; Park and Irvine, 1995). For Re<1 the viscosity would be:

$$\mu = g D_p^2 (\rho_p - \rho) t_p / 18L \qquad (7)$$

wheretp is the time required for a sphere to fall a distance, L.

Experimental Procedure

Figure (1) shows the system set-up of falling ball viscometer, The laser used in this work was diode green laser 532nm wavelength with100mW CW power and the detector is photodiode.

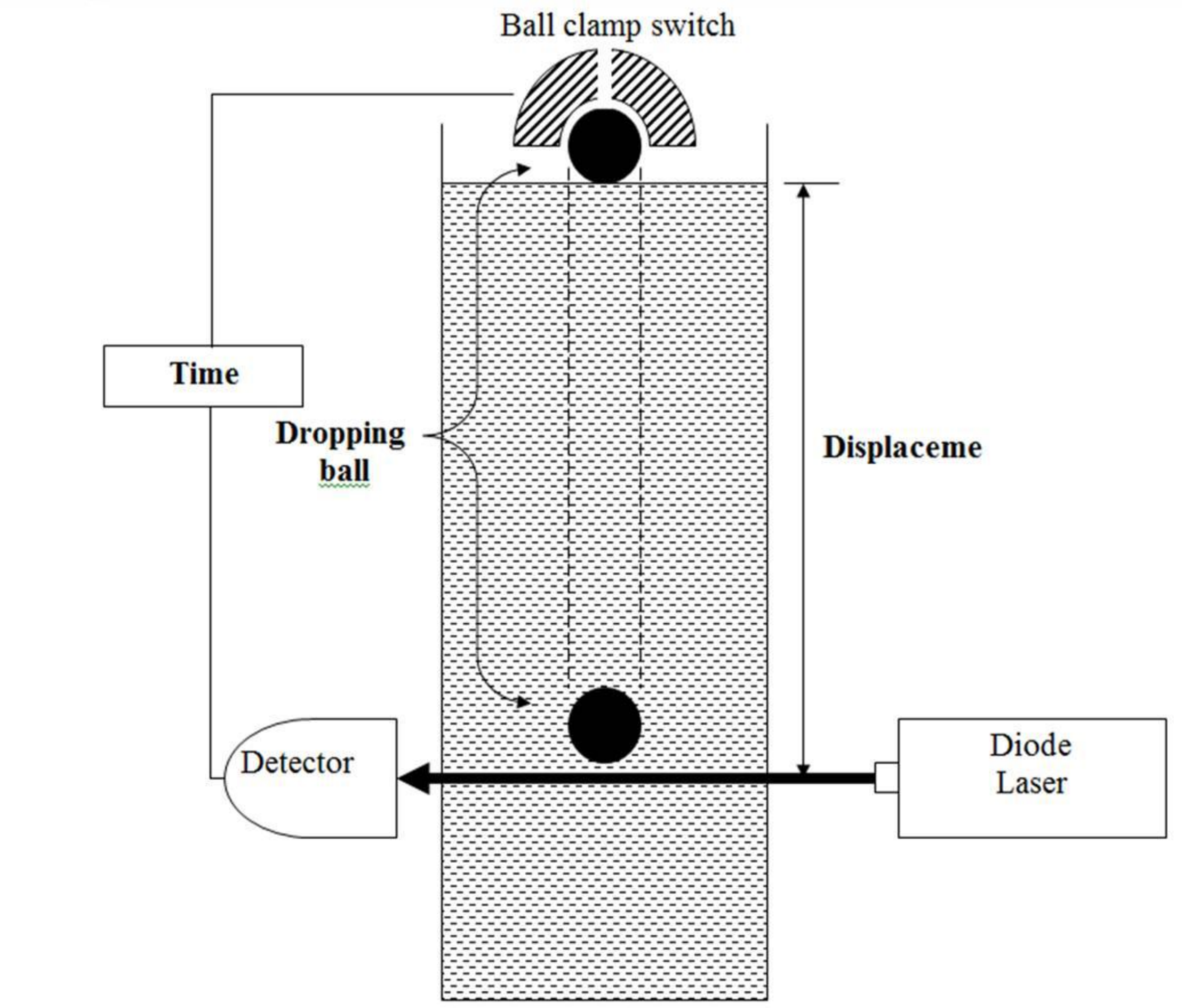

Figure (1): Falling ball viscometer system

The system configuration consisted of a vertical tube with diameter of 25mm and 1150mm height, and counter time. The ball was hold by a clamp switch.

The basic idea of the experimental set-up was to calculate the time duration at any distance along the tube, so the velocity of each ball can be easily determined with Equation (5), the time counter used is a sport stopwatch, which is interfaced with the ball clamp switch and photodetector to control dropping time of the ball. The algorithm process for recording time of the traveled ball is shown in the following block diagram:

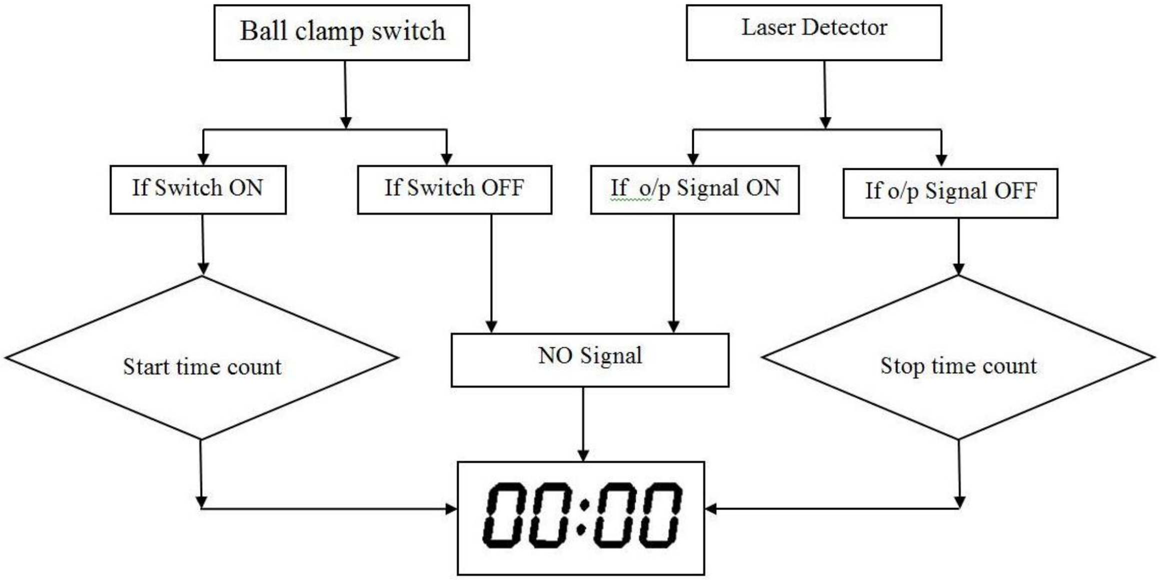

Figure (2): Block diagram of the recording time process

Six steel balls were prepared for the test with different diameter and weight as listed in table : with of (12mm, 10mm, 9mm, 8mm, 6.5mm and 5 mm). Each ball was dropped through the oil and at each ball trace a video was recorded in order to capture the photograph picture, the video camera must be closed to the vertical tube to get the best image, as shown in Figure (3) .

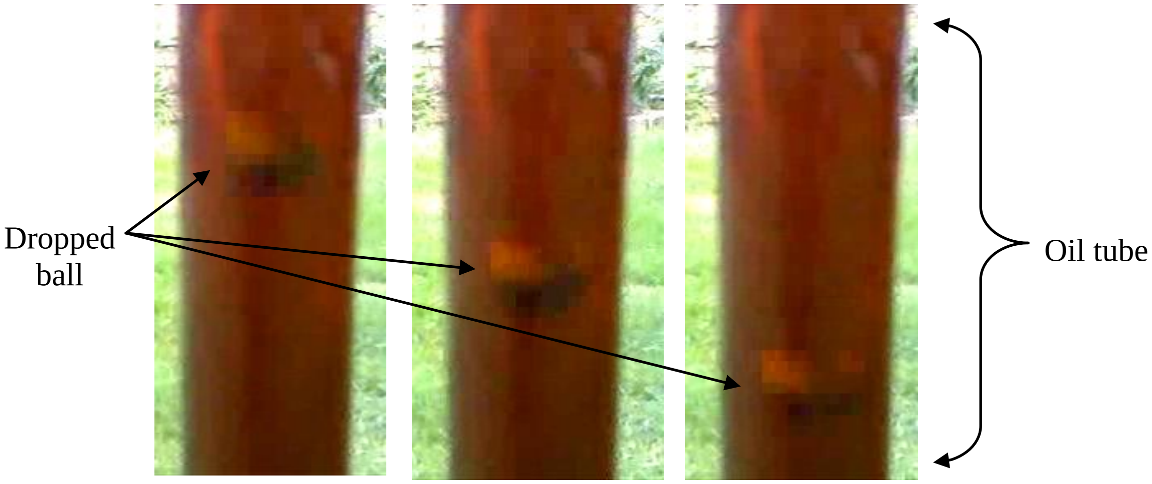

Figure (3): Photographic image of the dropped ball through oil tube

Measuring the Engine Particles Concentration

The Lambert law set-up was used to measure the absorption coefficient with concentration the set-up as shown in Figure (4) : The samples of oil engine were selected according the operation time of generator thus the operation time were taken as (1440, 2160, 2880, and 3600) hour.

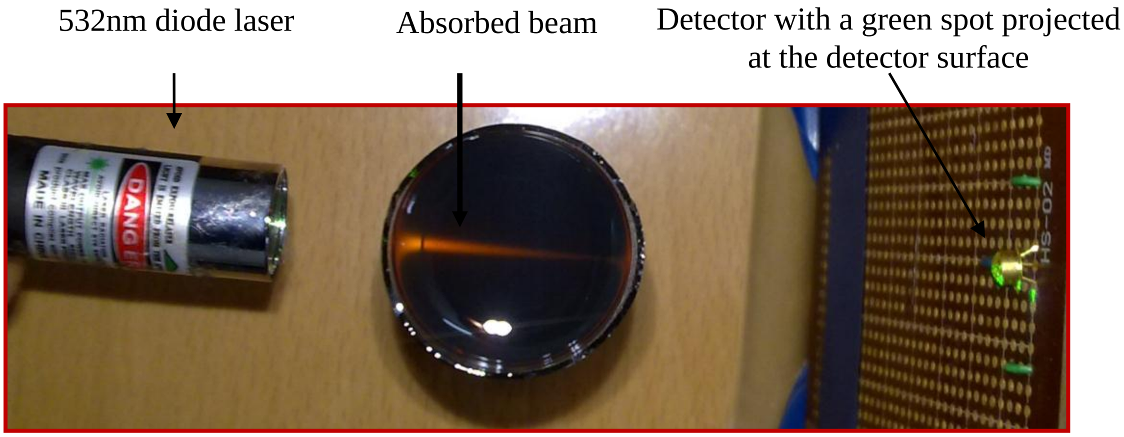

Figure (4): The optics set-up for measuring particles concentration.

The Beer-Lambert Law, relates the absorption of light to the concentration in solution (LeBlanc and Secco, 1994; Nasch *et.al.,* 1994):

$$\mathbf{A = \varepsilon bc = - \log (\%T)} \qquad (8)$$

Here **A** is the measured absorbance of the oil, ε is the molar absorptivity (with units of M-1 cm-1) the term was estimated by linear regression, **b** is the path length (in cm), and **c** is the concentration (molarity, or moles per Liter). The aligned set-up in Figure (4) is to determine the percent transmittance (%T), or how much light gets through oil.

Results and Discussion

All resulted data were obtained in order to compare the behaviors of variables at different cases. Figure (5) shows multiple behavior of dropped balls velocity with time, it is clearly observed that the large ball mass has higher velocity than other lower mass. In other words, the velocity increases with increasing time this is known as terminal velocity until reached at steady state velocity. Figure (6) present the experimental data of shear stress vs. shear rate, it is clearly observed that shear stress is directly proportional to the shear rate. The behavior of drag co. as a function Reynolds No. is shown in Figure (7), it was observed that the increasing in Reynolds No. will limit the drag co. which in turn affects the velocity of dropped ball. The variation of velocity with shear rate was introduced as in Figure (8).

Figure (9) presents the apparent absorption vs. operation time, it is clear that with increasing the engine operation time the absorption is increased and this is due to the variation in viscosity and density of oil and also due to the increased in the impurities produced by the friction of piston with hole cylinder inside the engine, this friction will tend to mix some particle of cylinder surface with oil. The concentration of these particles was calculated using Equation (8). Figures (10) show the behavior of absorption coefficient versus the concentration, while Figure (11) shows the increasing of the concentration with operation time.

Conclusion

It can be concluded that the measurements oil properties using vertical falling ball viscometer can be enhanced by using diode laser such that a good control time was obtained with an electronic arrangement that govern the duration time of the dropped ball. Therefore the diode laser can promise a new method for measurements many mechanical properties that can be make use of the laser beam to get the precise recording data for the measuring system.

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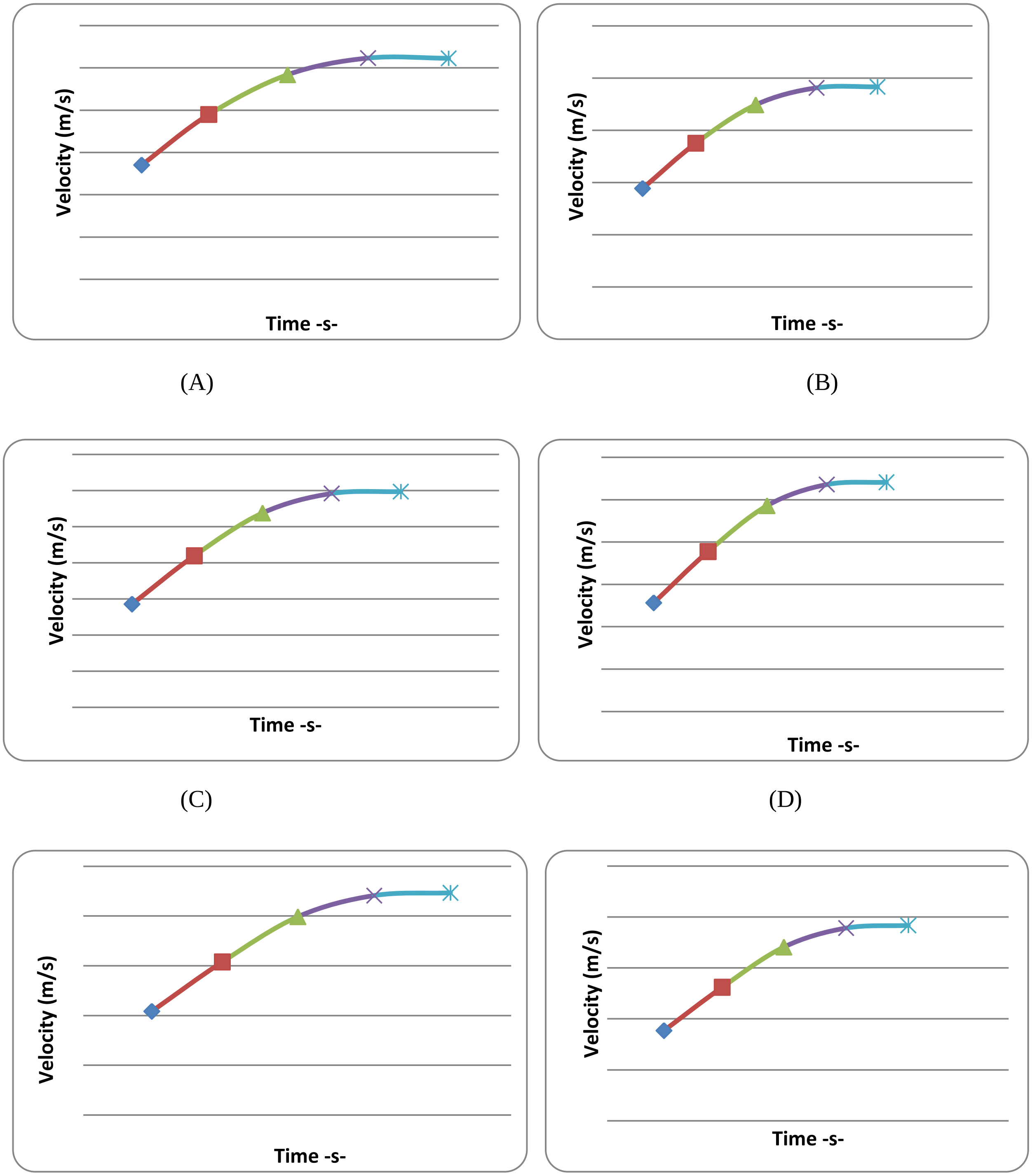
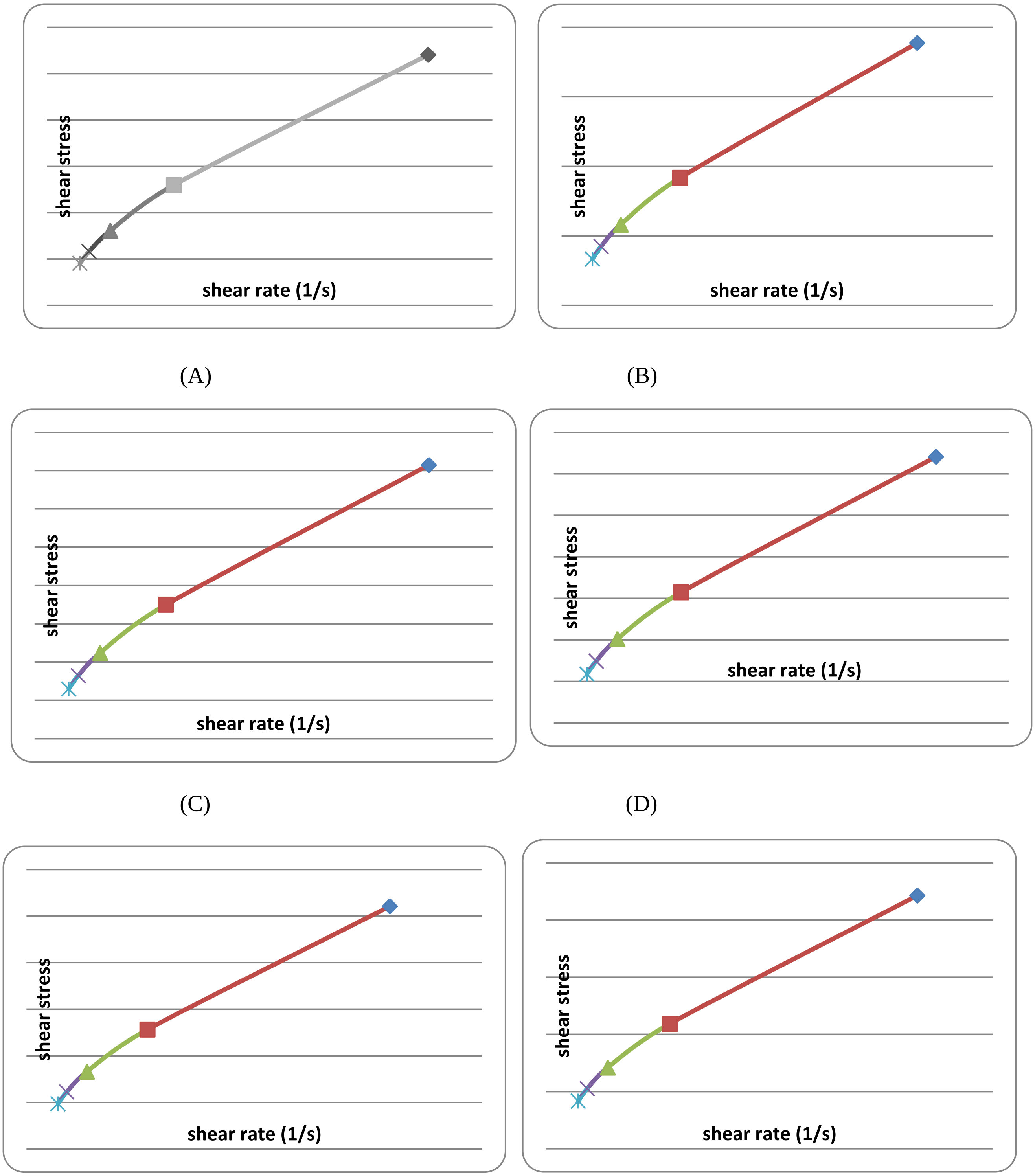


(A) (B)

(C) (D)

(E) (F)

Figure (5): velocity versus time stated at (A) high velocity lower time to (F)lower velocity with high dropping time.

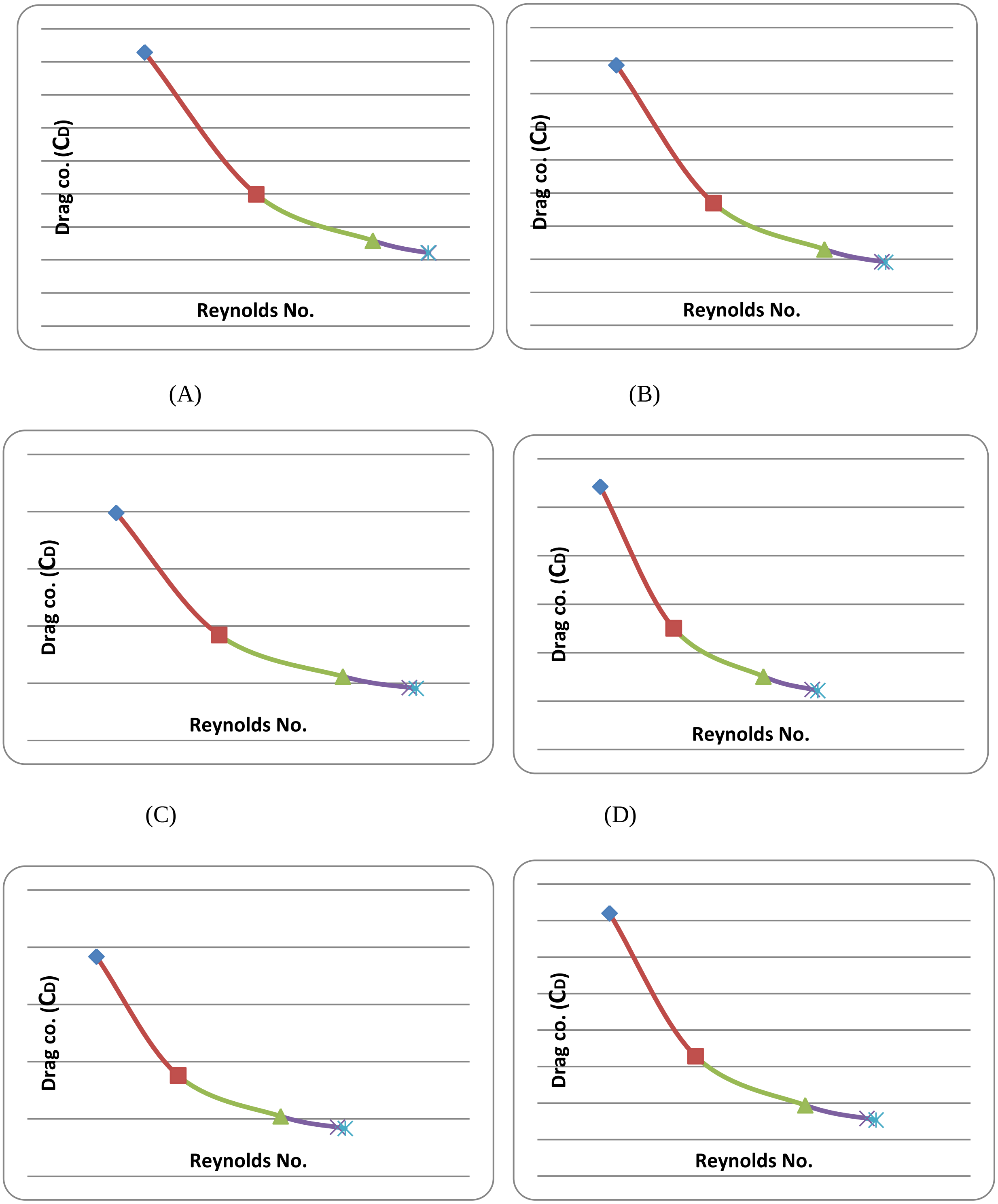


(A) (B)

(C) (D)

(E) (F)

Figure (6): shear stress versus shea rate



(A) (B)

(C) (D)

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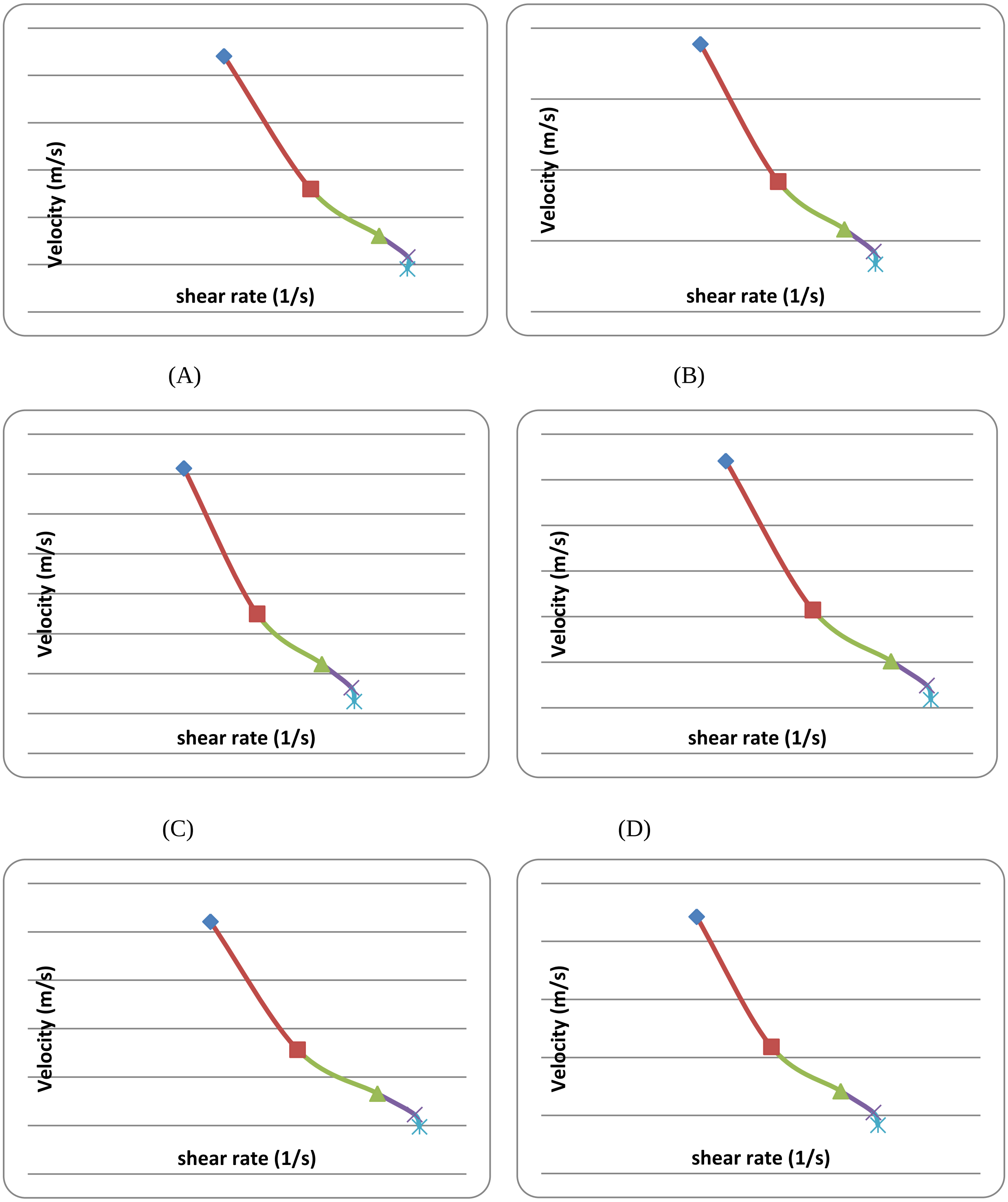
Figure (7): Drag coefficient versus Reynold number



(A) (B)

(C) (D)

(E) (F)

Figure (8): Velocity versus shear rate

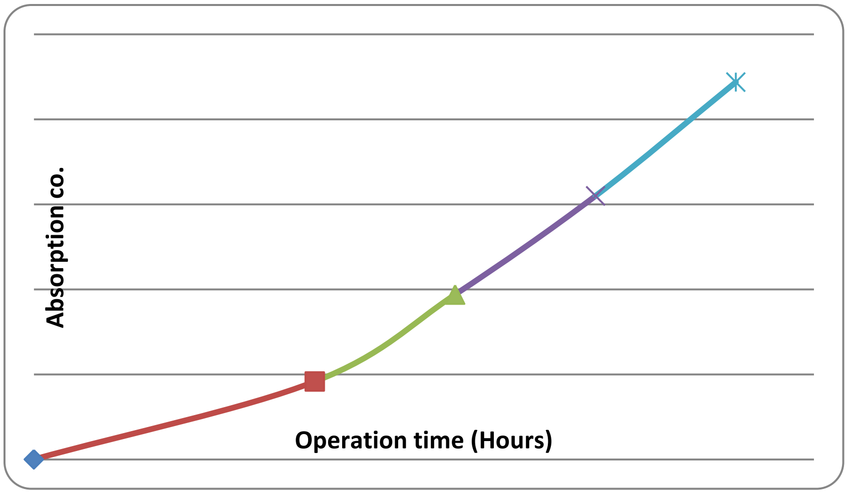


Figure (9): variation of absorption co. with operation time

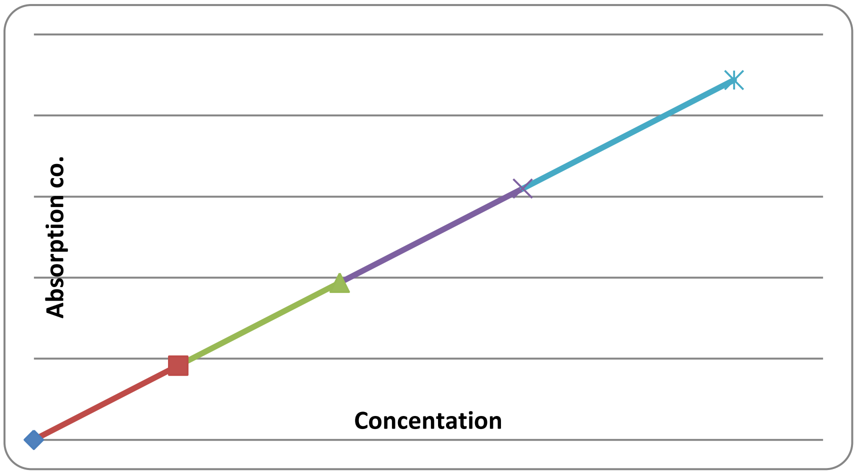


Figure (10): relation of absorption co. with concentration

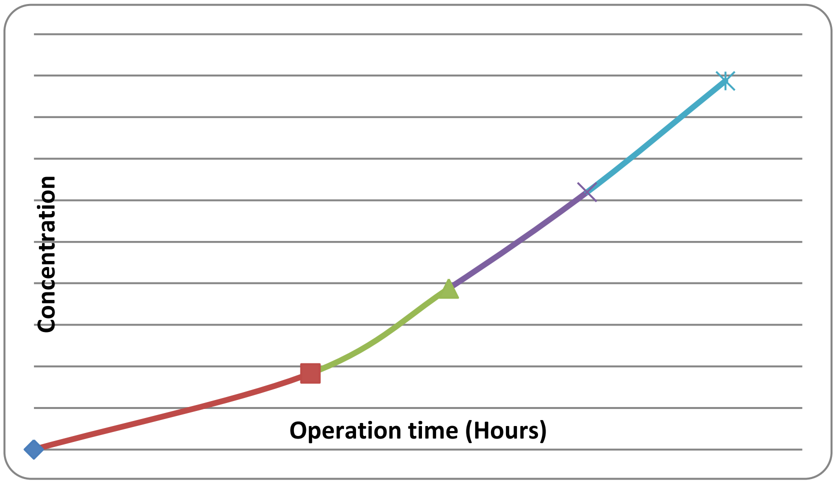


Figure (11): concentration behavior with operation time