The study effects of the characteristics of hydraulic oil on calibration of hydraulic pressure balance

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Abstract. One of the sources of an anomaly in the calibration of a hydraulic pressure balance is a various kind of working fluids that is employed in an operation. Therefore, the pressure and vacuum laboratory at National Institute of Metrology (Thailand), also known as NIMT, has been studied the effects of using different types of working fluids. The purposes of the study are to find piston effective area and study effectiveness of hydraulic pressure balance by observing falling rate and piston rotating time. The studies were performed in two ranges which are between 40 bar to 70 bar, and 600 bar to 700 bar. The results illustrate that the effective area of piston in the range of 40 bar to 70 bar has the maximum difference of 14 ppm, and in the range of 600 bar to 700 bar, it has the maximum difference of 5 ppm which will not affect the accuracy of hydraulic pressure balance. In addition to that, hydraulic pressure balances that use DHS oil have a falling rate approximately double of hydraulic pressure balances that use ISO VG 22 oil. Regardless, this does not affect the calibration result also the usage of the equipment. As the result, these two oils can be used interchangeably in calibration of hydraulic pressure balance that used in industry sector.

1. Introduction
Hydraulic pressure balances that have been using in industry sector do not have high accuracy when they are compared to standard hydraulic pressure balances used in calibration laboratories. The difference between these two pressure balances are Piston Cylinder Unit (PCU) structure, material, and working fluid. These factors affect measurement precision of hydraulic pressure balance. Because of different working fluid, we cannot connect Unit Under Calibration (UUC) directly to laboratory standard. This causes complexity in calibration preparation to prevent mixing of working oils and any permeation into standard pressure balance. With this issue, National Institute of Metrology Thailand (NIMT) performed tests by using two types of oil with 6 sets of sample pressure balance and calibrated them by standard pressure balance that used only DHS as a medium to study the effect of oil type in calibration.

Nowadays, using Pressure Balance as a reference Standard to calibrate pressure devices in secondary laboratories and industry level laboratory is increasing. Therefore, the need of Pressure Balance calibration is also increasing inseparably. To be able to support those calibration needs, secondary laboratories have to develop their ability in Pressure Balance calibration with Cross float method. A hydraulic Pressure Balance typically uses hydraulic oil which can be different from one to the others in terms of fluid properties such as density and viscosity for instance [1]. Traditionally, domestic secondary laboratories use the same type of oil as the standard machine which could lead to error in calibration result of Pressure Balance and additional expense on extra oil for calibration. Therefore, the pressure laboratory at National Institute of Metrology (Thailand) as a leader in pressure metrology in the country foresee the necessity to study that issue for finding suitable and practical solution.
1.1. Theory hypothesis and research scope
There are 2 main properties of oil used in Hydraulic Pressure Balance that can affect machine efficiency and calibration result are 1). Oil density and 2). Oil viscosity. The oil density, $\rho_f$, will affect calculated pressure from Pressure Balance while the oil viscosity will affect Falling Rate and Rotation time of Pressure balance. From those 2 points above, then we can come up with hypothesis and study scope that how these 2 properties can affect the calibration result. If there is a significant effect to the calibration, this has to come up with solution or suitable prevention which is practical. The research scope of this study are:
1. Study the effect of using different type of oils which are Sebacate oil (di-2-ethylhexylsebacate, DHS) and Industrial oil (ISO VG 22) which is a general oil for Pressure Balance in calibration laboratories in domestic industry sector.
2. Investigate the value of Effective area ($A_p$) and Falling rate of Pressure Balance used in the calibration as in figure 1.
3. Equipments in the study are from the NIMT pressure laboratory and our customers.

![Figure 1. Sample of the equipment used in the experiment.](image)

1.2. Equipment used in the experiment
Pressure calibration equipments that were used in this study are Hydraulic Pressure Balances. One from NIMT pressure laboratory used as the reference standard and the other 6 that has different maximum pressure range which can be seen from table 1, NIMT pressure laboratory and our customers with their permission.

| No. | Max pressure range (bar) | Nominal effective area (mm$^2$) | Accuracy class (ppm) |
|-----|-------------------------|---------------------------------|---------------------|
| 1   | 40                      | 40.3                            | 80                  |
| 2   | 60                      | 80.6                            | 80                  |
| 3   | 70                      | 80.6                            | 80                  |
| 4   | 600                     | 8.0                             | 50                  |
| 5   | 700                     | 8.0                             | 50                  |
| 6   | 700                     | 8.0                             | 50                  |
2. Experimental procedure
Each of sample Pressure Balance was installed to the standard Pressure Balance of the pressure laboratory as can be seen from figures 2 and 3. The calibration procedure of the experiment followed the guideline of EURAMET cg-3 Calibration of Pressure Balance Version 1.0 (03/2011) [2]. For the first round of calibration, a sample pressure balance was calibrated and measured a falling rate by using the same type of oil with the standard pressure balance which is Sebacate oil. After that in the second round, the sample pressure balance working fluid was replaced with ISO VG 22, and then the calibration and the measurement as in the first round was repeated.

![Figure 2. Installation diagram of the sample equipment during the experiment in the case of using Sebacate oil.](image)

![Figure 3. Installation diagram of the sample equipment during the experiment in the case of using ISO VG 22.](image)

After that perform pressure balance calibration by finding equilibrium point of both pressure balances. Then calculate effective area of sample pressure balance (UUC) by using the following equation (1) [2].

\[
P_e = \frac{\sum_{i=1}^{n} m_i \left( 1 - \frac{\rho_f}{\rho_{mi}} \right) g + V (\rho_f - \rho_a) g + C}{A_0 \left( 1 + AP' \right) \left[ 1 + \left( \alpha_p + \alpha_c \right) (t_p - 20) \right]} + \left( \rho_f - \rho_a \right) g \Delta h
\]

Where

- \( P_e \) = Gauge pressure at the instrument reference level, Pa
- \( P' \) = Approximate pressure, Pa
- \( m_i \) = Individual mass value of each weight on the piston assembly, mass value of the piston and carrier are included, kg
- \( \rho_f \) = Density of fluid, kg.m\(^{-3}\)
- \( \rho_a \) = Density of air, kg.m\(^{-3}\)
- \( \rho_{mi} \) = Density of each weight, kg.m\(^{-3}\)
- \( g \) = Local gravitational acceleration, m.s\(^{-2}\)
- \( C \) = Surface tension correction, N
- \( V \) = Buoyancy & fluid head correction, m\(^3\)
- \( A_0 \) = Effective area of PCU at atmospheric pressure and 20 °C, m\(^2\)
\( \lambda \) = Pressure distortion coefficient of the PCU, Pa\(^{-1}\)  
\( \alpha_p \) = Linear thermal expansion coefficient of the piston,  
\( \alpha_c \) = Linear thermal expansion coefficient of the cylinder, (\( \alpha_p + \alpha_c \)), °C\(^{-1}\)  
\( t_p \) = Temperature of the PCU during the pressure determination, °C  
\( \Delta h \) = Difference between the altitude \( h_1 \) of the balance reference level and the altitude \( h_2 \) of the point where the pressure has to be measured, m

Samples of pressure balances that were used in the study can be classified into two pressure ranges which are 40 – 70 bar and 600 – 700 bar. Each range has three samples of pressure balance which has accuracy of 80 ppm and 50 ppm respectively.

This study has been used two types of oil which are Sebacate oil (di-2-ethylhexylsebacate, DHS) and ISO VG 22. These two oils have different properties as can be seen from table 2.

**Table 2.** Properties of oils that were used in this work [3].

| Fluid                                      | Density (kg/m\(^3\)) | Viscosity (cSt) | Surface tension (N/m) |
|-------------------------------------------|-----------------------|-----------------|-----------------------|
| Sebacate oil (di-2-ethylhexylsebacate, DHS)| 915 @ 20 °C           | 21.5 @ 20 °C    | 3.1x10\(^{-2}\)       |
| Industrial oil, ISO VG 22                 | 870 @ 20 °C           | 46 @ 20 °C      | 3.0x10\(^{-2}\)       |

In addition to that the standard pressure balance used only DHS as a working fluid while all UUCs used both type of oils to see whether or not the type of oil will effect on effective area of piston.

### 3. Experimental result

This experimental result has 12 measurement data set. Each set consists of effective area and falling rate value of 6 PCUs. Each PCU has 2 sets of data that come from two types of oil as can be seen from table 3. Moreover, differences of effective area are shown in figures 4 and 5 for maximum pressure range 40 to 70 bar and 600 to 700 bar range respectively.

**Table 3.** Effective areas from the experiment.

| No. | Maximum pressure range (bar) | ISO VG 22  | Sebacate (DHS)  | \( UA_0 \) | \( UA_0 \) | EN Ratio | \( \Delta A_0 \) | Accuracy |
|-----|-----------------------------|------------|------------------|----------------|----------------|-----------|----------------|----------|
| 1   | 40                          | 40.31769   | 0.0031           | 40.31824       | 0.0020         | -0.1      | 14            | 80       |
| 2   | 60                          | 80.65750   | 0.0042           | 80.65749       | 0.0040         | 0.0       | 0             | 80       |
| 3   | 70                          | 80.63472   | 0.0035           | 80.63574       | 0.0034         | -0.2      | 13            | 80       |
| 4   | 600                         | 8.064277   | 0.0004           | 8.064262       | 0.0004         | 0.0       | -2            | 50       |
| 5   | 700                         | 8.054225   | 0.0004           | 8.054262       | 0.0005         | -0.1      | 5             | 50       |
| 6   | 700                         | 8.071241   | 0.0005           | 8.071260       | 0.0005         | 0.0       | 2             | 50       |
Figure 4. Differences of effective area for maximum pressure range 40 bar to 70 bar.

Figure 5. Differences of effective area for maximum pressure range 600 bar to 700 bar.

Table 4. Falling rates and rotation time from the experiment.

| No. | Maximum pressure range (bar) | ISO VG 22 Falling rate (mm/min) | Rotation time (min) | Sebacate (DHS) Falling rate (mm/min) | Rotation time (min) | ΔFalling rate (%) |
|-----|------------------------------|---------------------------------|---------------------|-------------------------------------|---------------------|------------------|
| 1   | 40                           | 0.11                            | >3                  | 0.27                                | >3                  | 59               |
| 2   | 60                           | 0.20                            | >3                  | 0.24                                | >3                  | 17               |
| 3   | 70                           | 0.40                            | >3                  | 1.00                                | >3                  | 60               |
| 4   | 600                          | 1.80                            | >3                  | 2.30                                | >3                  | 22               |
| 5   | 700                          | 0.18                            | >5                  | 0.40                                | >5                  | 55               |
| 6   | 700                          | 0.65                            | >5                  | 1.20                                | >5                  | 46               |
4. Conclusion

From the experiment, it can be surely concluded that usage of both oils does not affect error of pressure balance because the maximum difference of effective area is only 14 ppm which is less when compared to accuracy of pressure balance (UUC) at 80 ppm. Even though changing between two oils is not affect accuracy of UUC during calibration procedure but it will affect effectiveness of the pressure balance when used Sebacate oil instead of ISO VG 22, since it will make the falling rate of piston increase much higher because of difference of oil viscosity as can be seen from table 4. Result from the experiment shows that the difference effective area in each set has the maximum difference of 14 ppm and EN Ratio has the maximum value of 0.2 which definitely will not affect accuracy of Pressure Balance that has an accuracy of 80 ppm for the measurement range of 40 bar – 70 bar, also the accuracy of 50 ppm for the range of 600 bar – 700 bar. Nevertheless, the oil changing will affect a Pressure Balance efficiency such as increasing of falling rate when using Sebacate oil because of differences in density and viscosity.

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References

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