slows down the locking up of plates and changes the variation of total torque. Furthermore, owning to the change of viscous torque, the fluctuation of total with large velocity is bigger than that with low velocity, which has effect on the impact of gear change and vibration of transmissions.

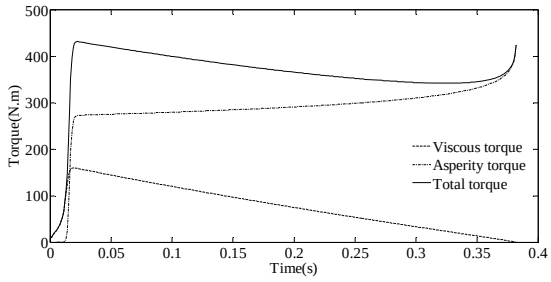


Figure 4. Effect of viscosity at 0.0419 Pa.s

### *B. Permeability of friction material effect*

Due to the porous structure and permeability of friction material, oil can be squeezed into contact facing by the hydrodynamic pressure during engagement. Permeability is also influenced by friction and wear conditions. Friction behavior is affected by the permeability in the initial engagement of wet clutches. Bigger permeability can lead to faster exuding velocity of oil film and more oil can be squeezed into the porous structure, leading to a longer engagement time. Fig. 6 shows the engagement behavior with low permeability at $4x10^{-13}$m. It is shown that the ascending curve of viscous torque is much smoother, compared with the simulation result in Fig. 1. The oil is hard to squeeze into friction material with low permeability, stored in the gap between friction plate and steel plate, which can support part of the applied load at the initial of engagement, causing a longer engagement time. Also, thanks to the stored oil in the gap, the duration time of viscous torque is long.

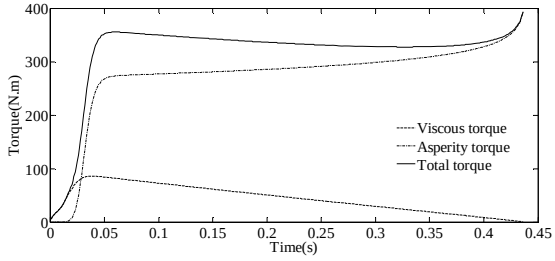


Figure 5. Effect of permeability at $4x10^{-13}$m

### *C. Applied Pressure Effect*

The applied pressure is a significant parameter for the engagement characteristics, largely influencing the engagement time. Oil film thickness decreases quickly with high applied pressure. The asperity force and torque increase when the oil film thickness reaches its constant value, so the ratio of angular velocity of steel plate increases, shortening the engagement time. Also, the viscous torque increases a little. Fig. 6 indicates that when the applied pressure increases, both of the asperity torque and total torque are bigger than that with lower applied pressure. The engagement time is 0.07s shorter than that in Figure. 1.

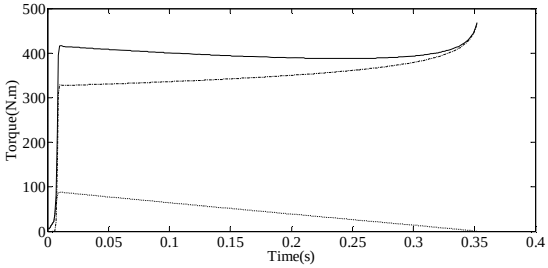


Figure 6. Influence of oil pressure at $1.2x10^{6}$ Pa

## V CONCLUSION

A mathematical model for the engagement of wet clutches was developed to predict the torque response during engagement of wet clutches. The modified Reynolds equation, including the effects of surface roughness, friction material permeability, and centrifugal force of oil in the gap of plates, was modeled to describe the hydrodynamic period of engagement. The transferred torque and velocity of steel plate can be obtained from the force balance equation and torque balance equation. The results show that viscosity affects the viscous torque, which can be concluded from the model theoretically. Also, the influence of applied pressure on engagement time is much bigger than other parameters. The material permeability has a great effect on both torque and engagement time. However, some parameters are not included in the model, such as thermal effect and grooves, which will be emphasized in the future research.

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