Torque and Compression Force of Pellicon® 2 and 3 Cassettes

Optimizing UF/DF Process Performance

Introduction

The installation of TFF cassettes into holder assemblies relies on compression to achieve the correct external and internal cassette sealing. In today's biopharmaceutical industry, two types of compression systems are typically used with cassette systems – Tie Rod/Fastener and Hydraulic Compression systems.

Figure 1. Tie Rod/Fastener System

Figure 2. Hydraulic Compression System

Either system can supply the correct compressive force to achieve cassette sealing. Each has advantages and disadvantages (**Table 1**).

Table 1. Comparison of Compression Systems

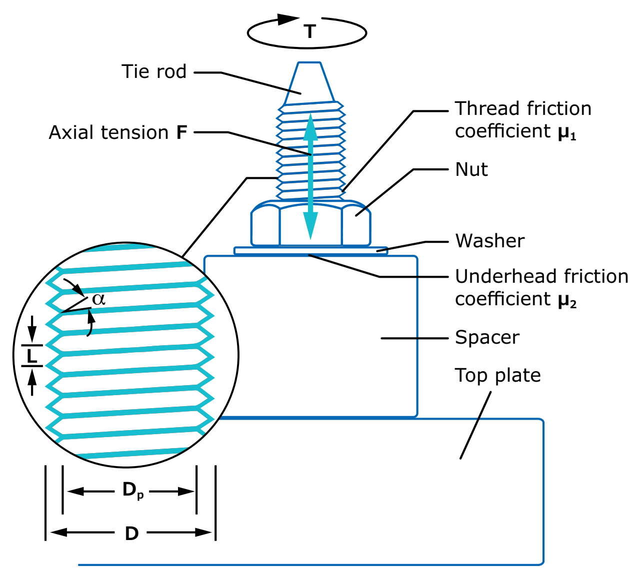
	Tie Rod/Fastener System	Hydraulic Compression System
Can achieve the right compressive force	✔	✔
Needs preventative maintenance	✔	✔
Low cost	✔	–
Compression monitored by SCADA	–	✔
Direct measure of compressive force	–	✔
Calibrated torque wrench required	✔	–
Faster closure	–	✔
Technique/training intensive	✔	–

This technical brief highlights how we determine the compression force for Pellicon® 2 and 3 cassettes in Pellicon® holders, as well as how we can help end users calculate torque and compression values if they are using other competitive holders.

Torquing and compression force

The design of Pellicon® 2 and 3 cassettes requires proper compression in a holder assembly for the internal and external seals to function correctly. For standard manual holders, this compression is supplied by applying torque to nuts on the threaded tie rods (**Figure 3**).

Figure 3. The applied torque to nut on the threaded tie rod on a Pellicon® holder is a function of several physical parameters



The relationship between torque and compressive force applied to the cassette is a function of the friction between the nuts, washers and threaded rods. Minimizing the friction maximizes the compressive force.

A gereral formula expresses the applied torque as function of several parameters is as follows:

$$T = F * \left(\frac{L}{2\pi} + \frac{D_p \mu_1}{2 \cos \alpha} + \frac{D \mu_2}{4}\right)$$

T	Torque per Nut
F	Force per Tie Rod
L	Pitch (mm/thread)
D_p	Pitch Diameter
D	Average mean Diameter of the Nut
μ_1	Coefficient of Friction (Under-Head Nut Threads/Nut)
μ_2	Coefficient of Friction (Underhead Friction)
α	One half thread angle

The formula is complex and the user must have knowledge of the physical parameters for the fasteners. While the threaded tie rod and nut characteristics can be easily retrieved from the literature, friction coefficients are often missed, especially as they are empirically defined. The formula also neglects other parameters linked to the characteristics of the material that are under stressed conditions (like torsion) when torque is applied.

A simplified formula, mostly used for rough evaluation of the required torque is:

$$T = F * \mu * D$$

T	Torque per Nut
F	Force per Tie Rod
D	Pitch Diameter
μ	Coefficient of Friction (Threads/Nut) in most cases between 0.15 and 0.3

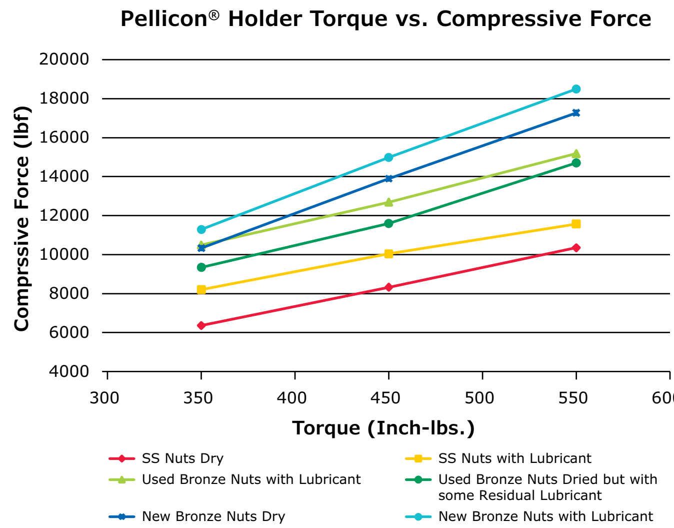
Based on this assumption, once the compression force per tie rod and the number of tie rods are known, the torque required to impart a compressive force can be calculated. Torque values will vary depending on the friction between the tie rod threads and nuts, and the friction between the faces of the nuts, washers, spacers and holder. These coefficients vary depending on age, cleanliness, lubrication, surface roughness, etc. Regular maintenance of the holder is strongly recommended (refer to Pellicon® 2 and 3 Filter Holders and Accessories User Guide (00109655PU)). It is important to understand the effect of the condition of the threads, type and selection of the nuts, and the presence of lubricant, can have on the actual applied compressive force.

Compressive force of 10,000–11,050 lbf (44–49 kN) is required for proper cassette sealing at working conditions.

Internal studies also revealed that the compressive forces are different case by case when applying the same torque to equipment but having different types of tie rods and/or lubricant conditions.

Figure 4 demonstrates that the hardware type and its maintenance conditions can significantly affect the compressive forces applied to the cassettes. Therefore care should be taken with the upkeep of the holders and hardware.

Figure 4. Holder conditions and torque have an impact on compression force.



The torquing procedure and specification (350–550 in-lbs or 40–62 Nm) as stated in the Pellicon® 2 and 3 Filter Holders and Accessories User Guide (00109655PU), reflects the proper range of torque to provide the right compression force.

Pellicon® cassettes assembled in other holders

When Pellicon® 2 and 3 cassettes are placed in other holders, the torque requirement to achieve the compression specification should be calculated. Typically Pellicon® cassette users ask for a torque value for the specific holder even when the main characteristics of the holder are not known.

Under-torque (under-compression) of cassette holders may cause internal by-pass (product passage from retentate to the permeate) or external leaks. Over-torque (over-compression) or unequal torque can result in high pressure drops and damage to the cassette scallop seals, causing loss of integrity. Our studies have shown that for Pellicon® 3 cassettes over-compressed to 22.000 lbs (700 in-lb torque), no water leaks were observed during water wetting of assembly and no cracks in jacket were observed during air integrity evaluation. It is however important to note that an under compressed cassette may well pass its air diffusion integrity test but still allow partial bypass to permeate when exposed to a pressurized fluid product stream.

We recommend 10,000–11,050 lbf (44–49kN) of compressive force to ensure internal and external sealing and proper operation of Pellicon® 2 and 3 cassettes.

It is recommended that when operating Pellicon® cassettes in competitive holders, one of our engineers should evaluate the holder assembly and dimensions to ensure successful operation. The following information is needed to develop a custom torque recommendation for these cassette/holder combinations:

- Sketch with holder dimensions or by preference a manufacturing drawing
- Number of tie rods and length
- Rod diameter and thread type including pitch
- A copy of the operating instructions supplied with the holder

When all data required by one of the above formula are known, an approximated value can be determined, and checked experimentally (i.e., a ramping integrity test to verify internal sealing at higher pressures or using through-hole bolt ("toroidial") load cells placed on all four rods between the spacer and the end plate in order to measure force for given torque in the holder.

Toroidial Load Cells

Please contact your local Account Manager who will help with the determination of the correct torque specification for your cassette and holder configuration.

Hydraulic closure

Hydraulic closure, with manual or automated controls, is intended for use with the Pellicon® cassette process scale holder. It will maintain appropriate pressure on the holder during processing and during storage of installed filter cassettes.

The main advantages of hydraulic compression include:

- **No torsion stress:** This method eliminates all "parasitic" torsion or bending stress in the bolt.
- **Accuracy:** The most important parameter, friction load, is controlled through the hydraulic pressure in the tensioner. The load does not depend on the various friction coefficients in the assembly.
- **No damage to components:** Internal stresses are controlled, and no friction is generated under heavy bearing pressure. Therefore this method protects the individual components of the assembly.
- **Easy decompression:** The decompression operation is extremely easy and saves time.
- **Simultaneous compression is possible:** This method allows simultaneous compression of several or all of the filter levels in a given assembly. The advantage is equal compression of the assembly, simplifying the process and reducing work time.
- **Process automation is possible:** When using a holder with hydraulic closure for Pellicon® 2 and 3 cassettes, the force is applied via hydraulic cylinders that convert the pressure generated from a hydraulic system pump into a linear force. It is important to note that the pressure value provided in documentation for hydraulic closure is that of the fluid in the piston, not directly the pressure on the cassettes themselves. This force generated by the cylinder is a product of its effective piston area and the hydraulic pressure as given by the following formula:

$$F = P * A$$

F Cylinder Force (lbf or N)
P Pressure (psi or bar)
A Effective Piston Area (in² or M²)

The two main variables to consider are the maximum available hydraulic pressure, the effective area of the piston and the number of cyclinders. On an existing system, the maximum hydraulic pressure may be constrained by existing components, such as the pump, valves or system power. Once the maximum available pressure is determined and the cyclinders force required for the application is known, the starting point for the calculation is the cyclinder's effective piston area.

Given that the hydraulic cylinder is typically mounted on a supporting rod, the effective area is equal to the annulus area of the cyclinder, or the piston area minus the rod cross-sectional area. The following formula is used to calculate the piston area per cylinder:

$$A_{pist} = \frac{\pi(d_p^2 - d_r^2)}{4}$$

A_{pist} Piston Area (in² or M²)
dp Piston Diameter (in or M)
dr Rod Diameter (in or M)

Most hydraulic holders use multiple cylinders. The effective area is the piston area multiplied by the number of cylinders:

$$A_{tot} = A_{pist} * n^o \text{ of Cylinders}$$

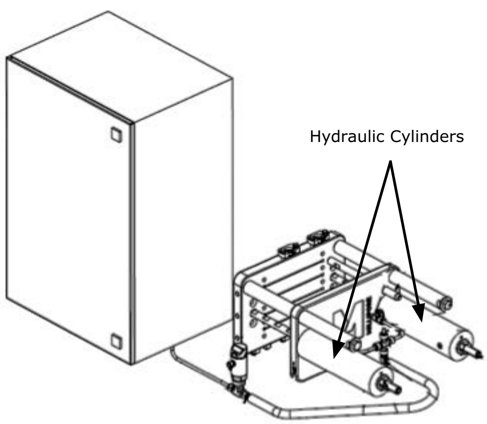
Once the area is known, the hydraulic system pressure is calculated to provide the required linear compression force on the holder. By rearranging the force equation above, pressure is determined from:

$$P = \frac{F_{req}}{A_{tot}}$$

Application example for hydraulic closure

We recommend that Pellicon® 2 and 3 cassettes be compressed within the holder at 10,000–11,050 lbf. (44–49kN). On our custom hydraulic systems and holders this translates to a hydraulic pressure of 1850–2050 psi. This pressure is converted to compressive force by hydraulic cylinders, which have a piston diameter of 2 inches (5.08 cm) and a rod diameter of 0.75 inches (1.9 cm). Further, the cylinders contain two springs that push against the hydraulic force at approximately 80 lbf combined. This spring force can be considered a system loss, and added to the 10,000–11,050 lbf required. The hydraulic system pressure is determined using these dimensions and the required hydraulic force.

Figure 5: Hydraulic Power Unit with Process Scale Pellicon® Cassette Holder



The effective area is calculated first:

$$A_{pist} = \frac{\pi[(2in)^2-(0.75in)^2]}{4}$$

$$A_{pist} = 2.70\ in^2$$

Two cylinders are positioned on the left and right sides of the holder end plate (**Figure 5**), mounted on supporting rods, therefore:

$$A_{tot} = 2.70\ in^2 \times 2 = 5.40\ in^2$$

The hydraulic system pressure is then determined and set:

$$P_{min} = \frac{F_{req}}{A_{tot}} = \frac{10,000\ lb}{5.40\ in^2} = 1851.9\ psi$$

$$P_{max} = \frac{F_{req}}{A_{tot}} = \frac{11,050\ lb}{5.40\ in^2} = 2046.3\ psi$$

Rounding off these values, the recommended hydraulic pressure setting for our systems and holders is attained:

$$P = 1850–2050\ psi$$

Pressure in psi can be easily converted to bar by considering 1 bar = 14.50377 psi.

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