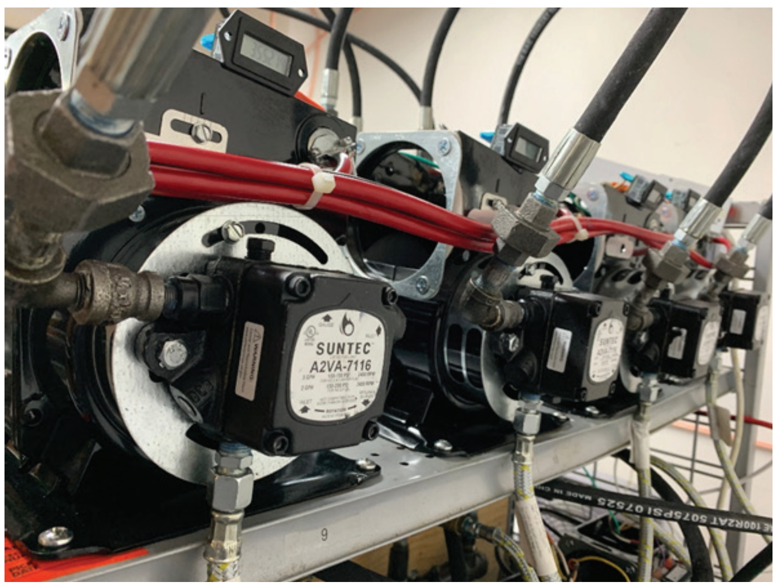
Report on Pump Cycling Test

August 24, 2020



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Introduction

The need to combat global warming has resulted in a shift toward the use of cleaner energy sources in many industries. The home heating industry faces such a shift as well. Various fuels have been investigated as lower greenhouse gas (GHG) alternatives to petroleum-sourced heating oil. Over the past 15 years, biodiesel has emerged as the most widely available and used of those alternatives. A number of heating oil marketers in the Northeast have already implemented the use of 20% biodiesel blend with heating oil (hereby referred to as B20, and BXX for any other percentage of biodiesel) as standard. Some are exploring delivery blends up to B100 to select customers. This is considered a vast shift in the industry because out of the reported 3.6 billion gallons of heating oil sold for space heating in the United States in 2018, 85% was consumed in the Northeast.[1] Therefore, any changes in the Northeast will strongly be projected onto the national market.

While biodiesel has similarities to pure petroleum-based heating oil, it is chemically different. This has raised concerns as to how existing equipment will perform when using higher blends of biodiesel. A particular topic of discussion is the fuel pump, which consists of various sub-components with elastomers that contribute to its overall operation. For example, the piston, which is responsible for controlling outlet pressure and providing clean cutoff, has an elastomer material on its "face" that is susceptible to damage. This study investigated the effects prolonged exposure to biodiesel may have on this and other parts of the pumps by cycling them up to 500,000 cycles with various blends of biodiesel up to B100. The number of cycles simulates ~50 years of field operation given an estimated ~10,000 cycles annually. The same tests were also performed on pumps with No. 2 heating oil (which can contain up to 5% biodiesel in the Downstate New York area; hence it will be called B5) as a control. There were also scheduled break points to examine the condition of the pumps visually and determine cutoff performance.

Experimental Setup

All tests took place at the National Oilheat Research Alliance lab in Plainview, NY. A test stand containing two sides, each with 8 burner chassis mounted on it was used for cycle testing. This provided the ability to test 16 pumps at once. Each side contained its own power and fuel supply. The top row (with 4 pump setups) of one of the sides is shown below:

[1] "Heating oil explained: Use of Heating Oil." *U.S. Energy Information Administration*. www.eia.gov.

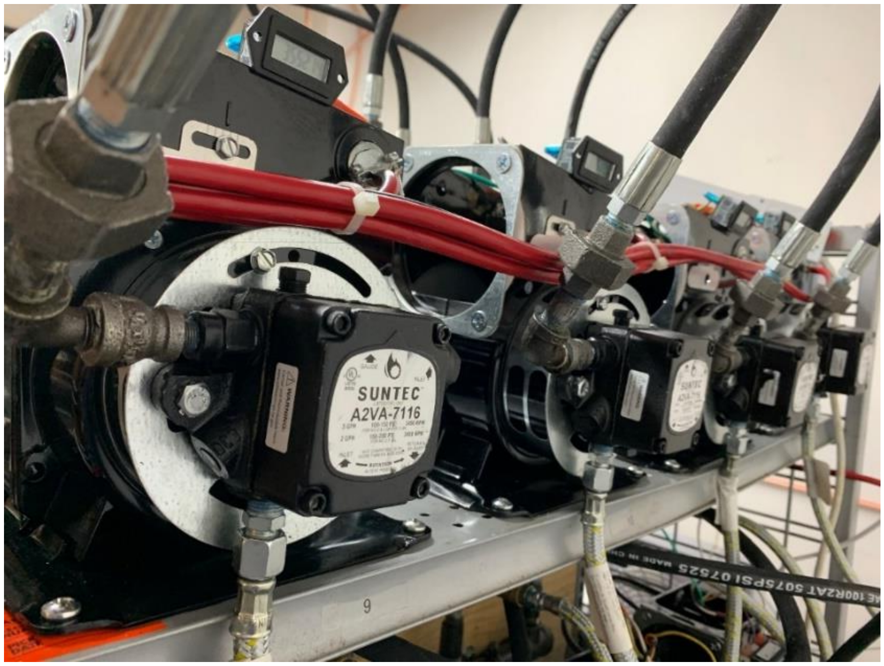


Figure 1: Top row of one of the sides of the test stand

The inlet fuel line at the bottom of each pump was connected to a common supply pipe, which then connected to the supply pipe for the bottom row and the main fuel reservoir that is stored in a 5-gallon container. The fuel was discharged on the top left of each pump into a high-pressure rated hydraulic hose that had a nozzle attached at the end of it. Each nozzle discharged fuel at different points into a common pipe and remained (partially or fully) submerged in the fuel at all times. This allowed the fuel to be sprayed into a volume of liquid rather than as a high-pressure discharge into the air. The common discharge pipe was angled in such a manner that allowed for gravity to assist the fuel flow return back into the main reservoir. The inlet and outlet piping were the same for another set of 4 pumps that was underneath the row shown in *Figure 1*. The system for the other side of the test stand was nearly identical, with the exception of the burner chassis used. The motors for all 16 pumps in the test stand were aftermarket replacement units manufactured by Century, model number OBK6002V1.

A Crouzet EMER8 timing relay switched power on and off for cycling the pumps for each row. The timer provided power (when switched on) to an electro-mechanical relay. Each row has its own mechanical and timing relay to minimize the electrical load on each relay. A Trumeter Model 34 counter was mounted on each chassis and connected in parallel with the motors to count the number of cycles.

For the purpose of taking pictures of the diaphragm seat and piston faces at scheduled intervals, a USB-connected camera by Opti-tekscope was used. Also performed at the scheduled intervals were cutoff tests. For these tests, each pump was mounted on a burner attached to a boiler at the NORA lab. This setup had various measurement and control instruments connected to it. Included in this setup was a simple circuit with a voltage source and a 1000Ω resistor connected in series with the cad cell of the burner. Voltage measurements across the source and the known resistance were made by a National Instruments data acquisition system and facilitated by a LabVIEW code connected to the system. The code then recorded and saved the voltage readings for use in further analysis. The data acquisition software and hardware provide the ability to perform high speed data recording of the voltages.

Test Procedure

All pumps used in this study were Suntec A2VA-7116 model, which is a very common pump in the field. It shares similar parts with other popular pumps such as the Beckett Cleancut and Suntec A2VA-3006, both of which contain a solenoid valve while the test model does not. According to the test plan, the test stand described previously was used to cycle the pumps at intervals of 5 seconds on and 5 seconds off – one full cycle consists of one on and off period or ~10 seconds. Each pump was cycled up to 500,000 times, with scheduled removal and testing performed at 100,000, 200,000 and 350,000 cycle break points. Conservative estimates place a value of 10,000 cycles performed by an average pump in a home annually. The scope of this test, by that metric, then simulated 50 years of operation in the field for each pump. Pump models other than the test pump (including the ones mentioned above) were considered for this test but were not included. There are plans to include those units in a future test as part of Phase 2 of this study.

Following removal at each break point, the pumps were inspected visually, and pictures were taken of the piston face and the seat of the diaphragm valve. It must be noted that diaphragm seat pictures were not taken at the intermediate intervals for all pumps. The distance from the camera to the object pictured were kept constant from one picture to another by using indicators on the height altering mechanism of the camera. The inclusion of multiple stops between the start and ending of the test was intended to document gradual, time- and cycle-dependent degradation, if any, of these parts. Other parts not pictured but only monitored anecdotally included the strainer, cover gasket and gearsets. Pictures of these parts were only taken when a buildup of degraded fuel or polymers were observed. The cone valve in the pumps was not inspected in any manner and, therefore, have been left out of any discussion in this report.

Once pictures of the relevant parts had been taken, each pump was put on a burner to perform a cutoff test. This test recorded cad cell resistance at a high sampling rate to determine how long it takes the pump to completely stop the flow of fuel after the burner motor turned off. This time was identified by a variation in cad cell resistance from the operational range during steady-state operation. During the test, steady-state operation was achieved by providing an adequate domestic hot water load to the boiler. This was done once for 5 minutes to ensure any remaining air in the nozzle line of the pump was removed. Following this, a rest period of 5 minutes was applied, and then the load was turned on again for 10 minutes. An extra 5 minutes of data recording occurred following this load application for the boiler to reach its target temperature and shut off. Any damage or degradation to the parts, especially piston and diaphragm seat, over time would appear in the data as a long cutoff period. The acceptable range for this test was determined to be within 1 second. Generally, previous testing on pumps used in the field yielded cutoff times within 0.5 seconds.

The fuel in each reservoir on the test stands was changed once a week since recirculation through the system over time could degrade the fuel rapidly. This was done as a precaution to avoid degraded fuel from causing failure, since it would be hard to distinguish from any other causes of failure. Previous tests at the NORA lab on fuels before and after cycling for a week in similar conditions to this test have shown high fuel degradation rates in recirculation tests, suspected to have occurred due to exposure to high temperatures in the pumps followed by cooler temperatures in the container (refer to Appendix A).

Results

The pumps were removed from the test stand at the scheduled break points. The cutoff time for each pump was determined based on the cad cell resistance at the end of the final steady-state cycle of the cutoff test mentioned earlier. The cutoff times for each pump from each removal period are shown in *Table 1*.

Table 1: Cutoff times for all tested pumps at each break point

		Cutoff Time (s)			
Fuel	Pump Number	100,000	200,000	350,000	500,000
B0	1	0.3	0.3	0.4	0.4
	2	0.4	0.4	0.5	0.3
	3	0.2	0.2	0.3	0.3
	4	0.4	0.4	0.1	0.2
	5	0.1	0.2	0.4	0.1
	6	0.2	0.1	0.4	0.3
	7	0.4	0.2	0.2	0.1
	8	0.4	0.4	0.4	0.1
B20	17	0.3	0.1	0.2	0.2
	18	0.3	0.1	0.4	0.4
	19	0.2	0.2	0.2	0.4
	20	0.4	0.2	0.2	0.3
	21	0.2	0.2	0.3	0.3
	22	0.3	0.4	0.3	0.4
	23	0.2	0.3	0.3	0.2
	24	0.2	0.2	0.4	0.3
B50	25	0.2	0.3	0.2	0.1
	26	0.3	0.2	0.2	0.2
	27	0.2	0.2	0.1	0.1
	28	0.3	0.5	0.2	0.1
	29	0.3	0.1	0.2	0.2
	30	0.3	0.1	0.4	0.2
	31	0.4	0.2	0.2	0.3
	32	0.2	0.1	0.3	0.3
B100	9	0.4	0.4	0.4	0.2
	10	0.2	0.3	0.3	0.2
	11	0.3	0.5	0.4	0.2
	12	0.1	0.2	0.5	0.2
	13	0.4	0.3	0.2	0.2
	14	0.3	0.3	0.1	0.6
	15	0.3	0.5	0.1	0.6
	16	0.5	0.2	0.2	0.2

The results in the table should not be taken as a comparison between one pump to another. They should instead be used as a general guideline to determine if the piston (and other related parts such as diaphragm seat) was operating properly. A cutoff time of 1.0 second or greater was chosen to be a range above which the cutoff system would be deemed problematic in this study. All results determined were below that range. The worst-case scenario from the data were cutoff times of 0.5 and 0.6 seconds. These numbers are not out of the ordinary for pumps without a solenoid valve.

Along with the cutoff test, pictures of the piston face were taken at every scheduled stop. The pumps with the worst results from the cutoff tests were examined very closely but were determined not to contain more damage than other pumps that had performed better in the cutoff test. The piston faces that showed the most physical damage after 500,000 cycles are shown below:

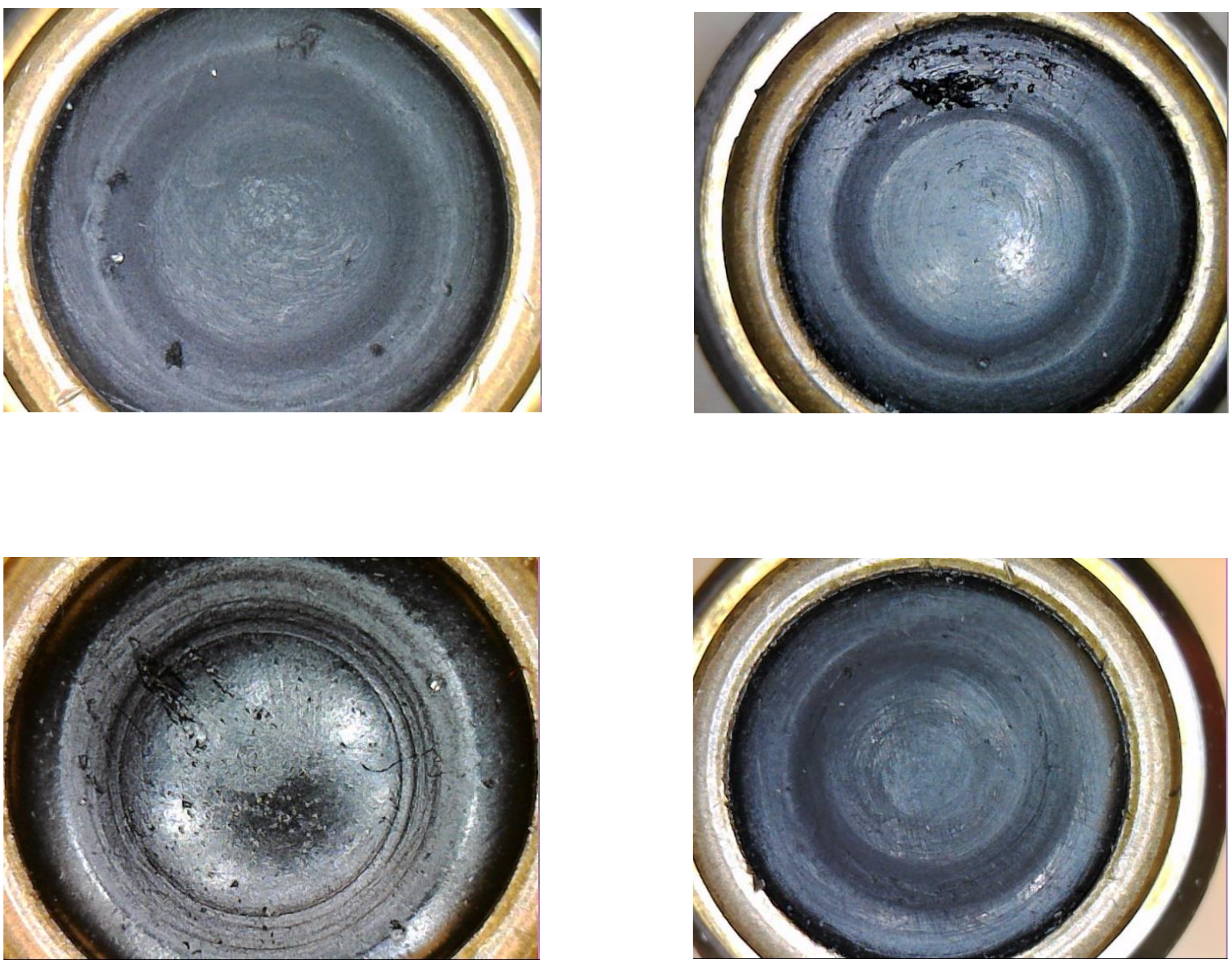


Figure 2: Piston faces with most apparent wear and tear after 500,00 cycles of pumps that operated with B5 (top-left, pump 5), B100 (top-right, pump 9), B20 (bottom-left, pump 17) and B50 (bottom-right, pump 30)

For comparison, a few more piston faces from pumps that cycled with B5 and some that cycled with B100 are shown in *Figures 3* and *4* below:

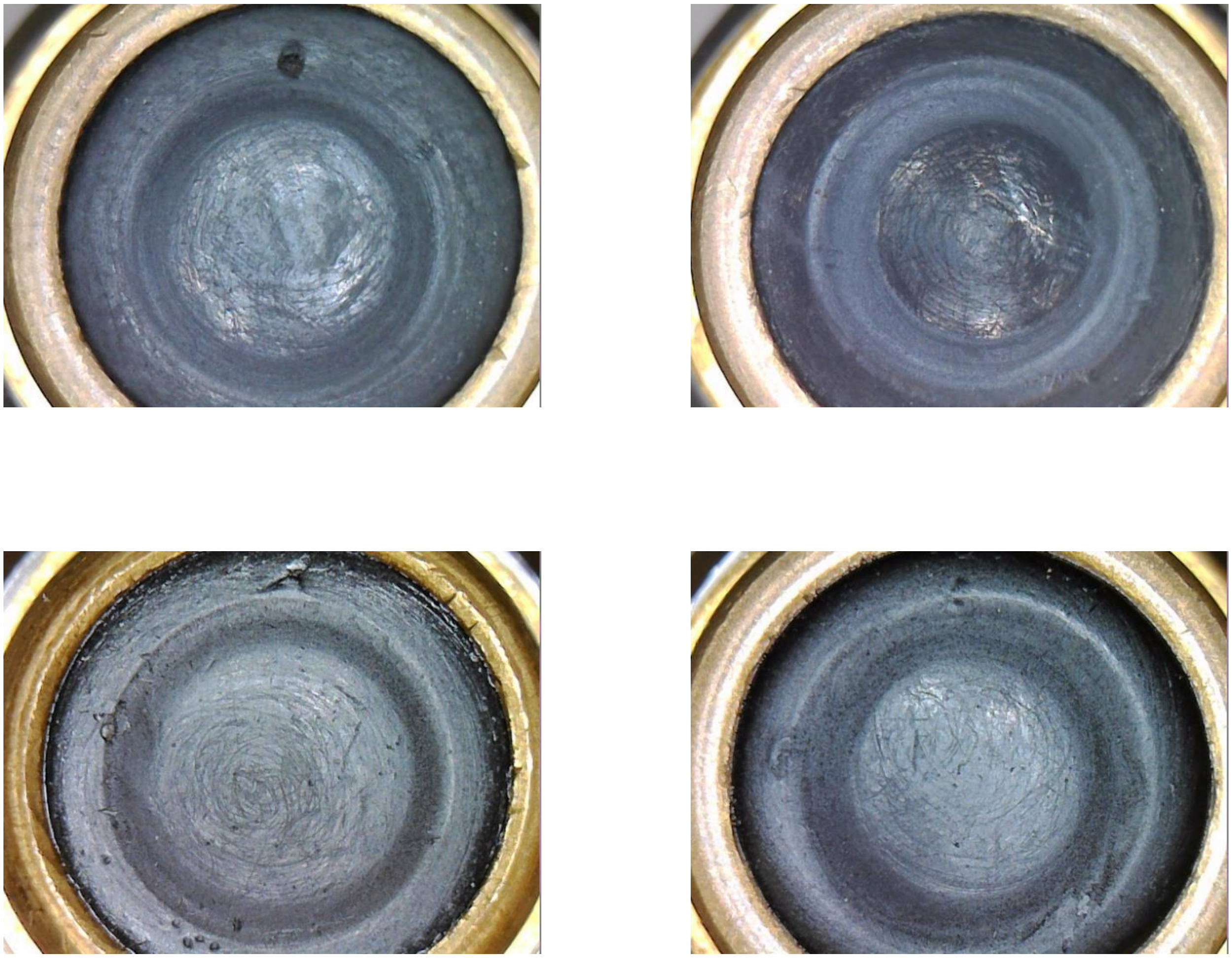


Figure 3: Piston faces from four other pumps that cycled 500,000 times with B5

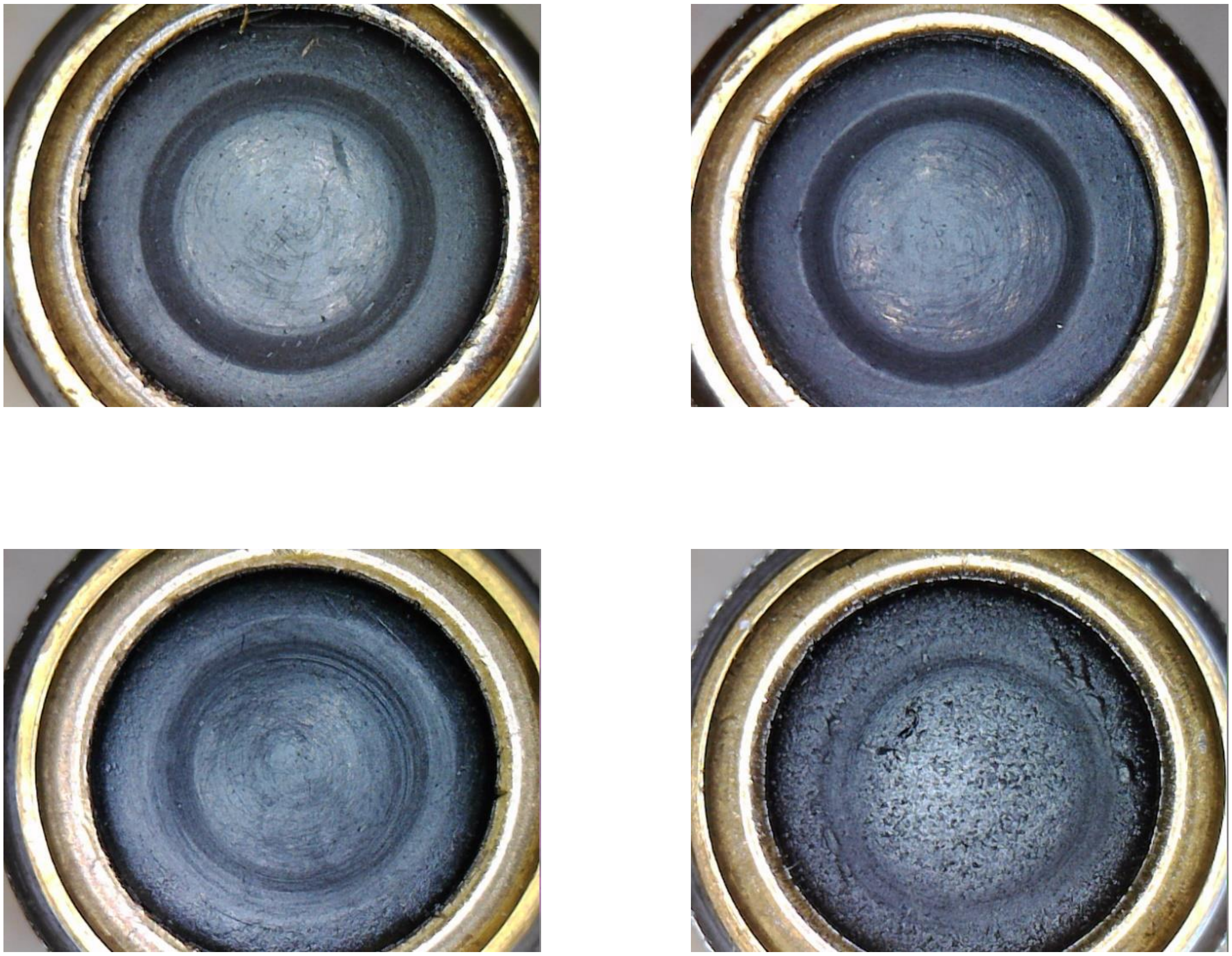


Figure 4: Piston faces from four other pumps that cycled 500,000 times with B100

Diaphragm seat pictures were also taken during the break points, but only for the pumps that were tested with B5 and B100. Pictures of this part for the pumps that were tested with B20 and B50 were only taken after 500,000 cycles were completed. The following are worst-case scenario pictures of the diaphragm seats for each fuel after 500,000 cycles:

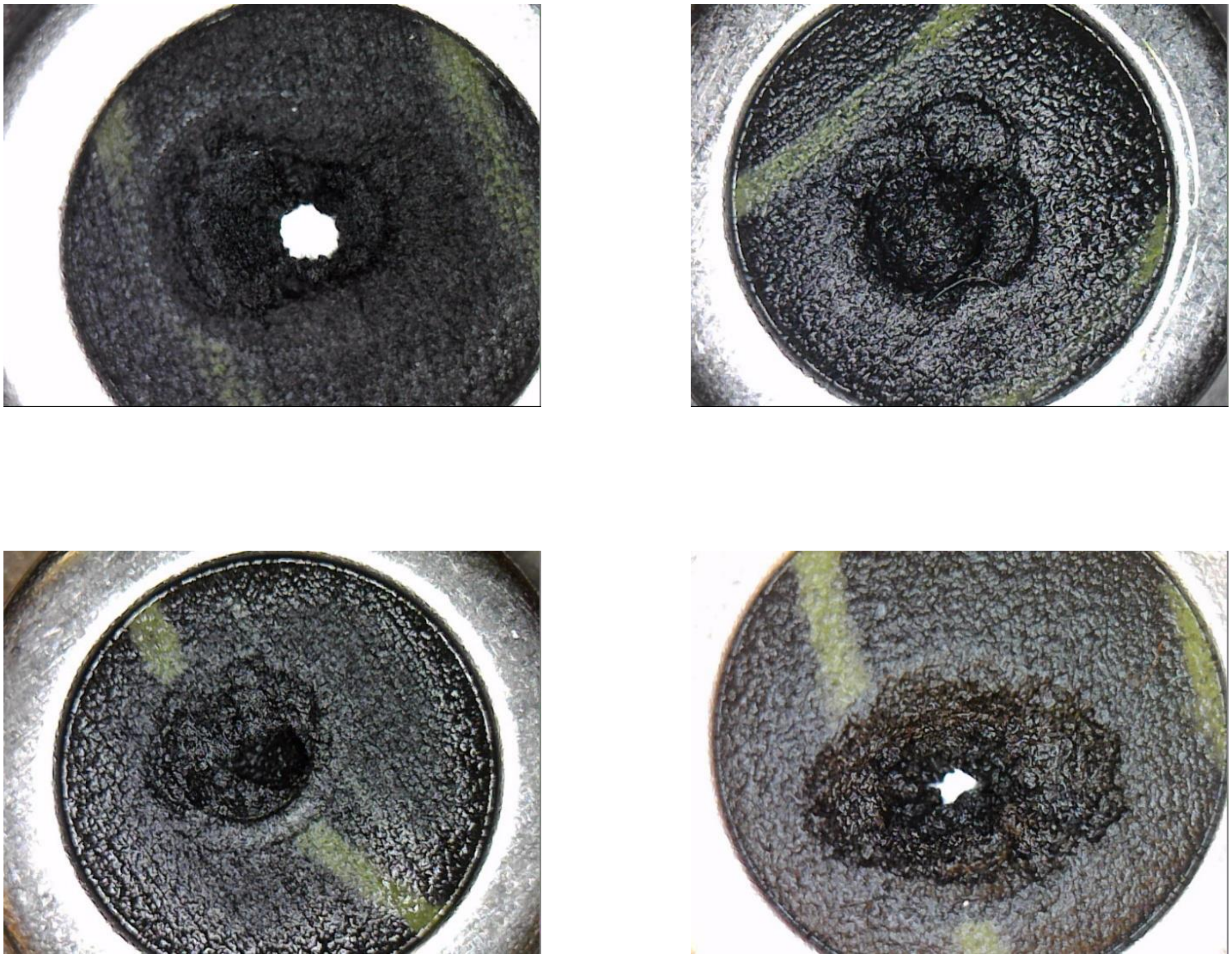


Figure 5: Diaphragm seats with most apparent wear and tear after 500,00 cycles of pumps that operated with B5 (top-left), B100 (top-right), B20 (bottom-left) and B50 (bottom-right)

For comparison, a few more diaphragm seats from pumps that cycled with B5 and some that cycled with B100 are shown below:

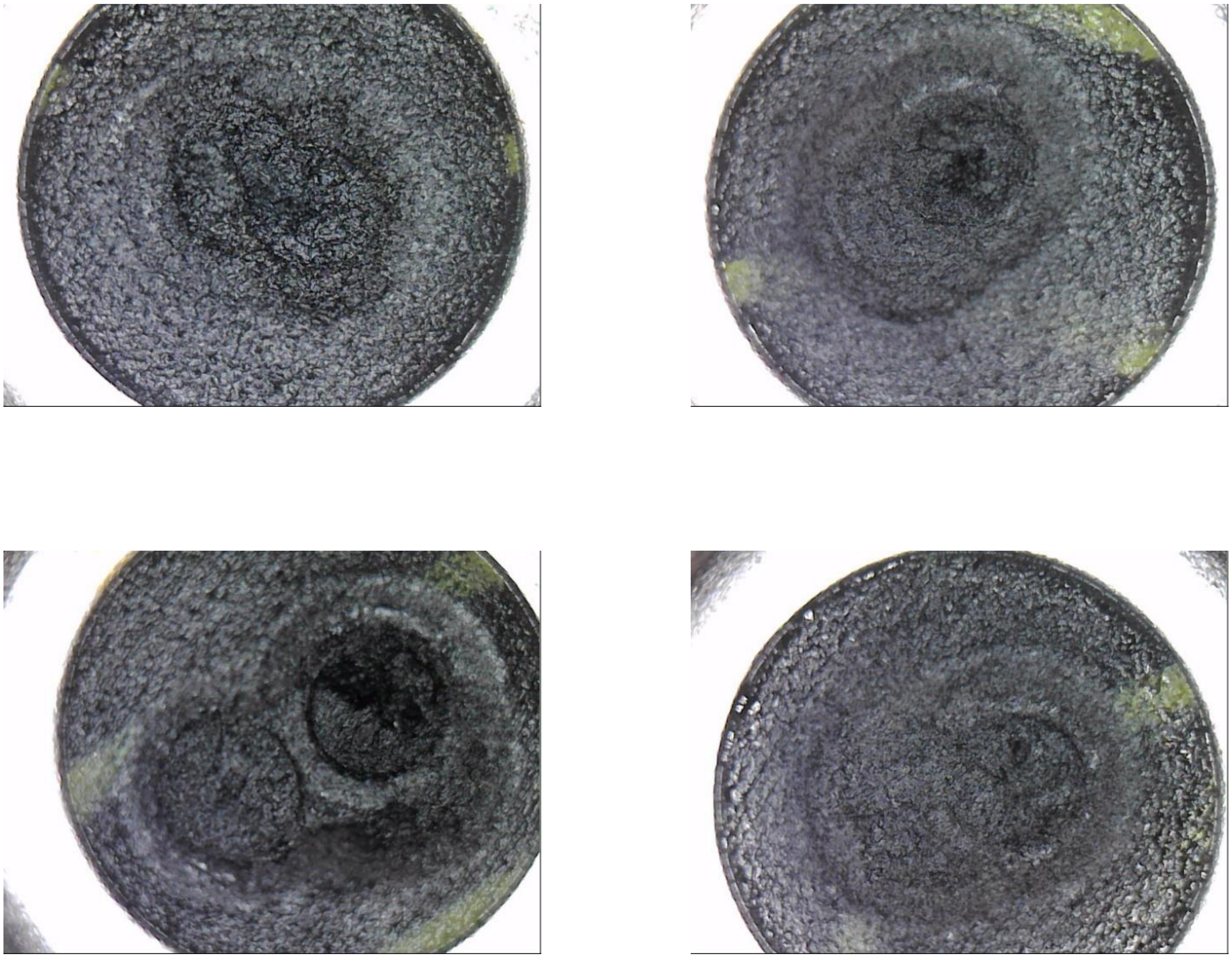


Figure 6: Diaphragm seats from four other pumps that cycled 500,000 times with B5

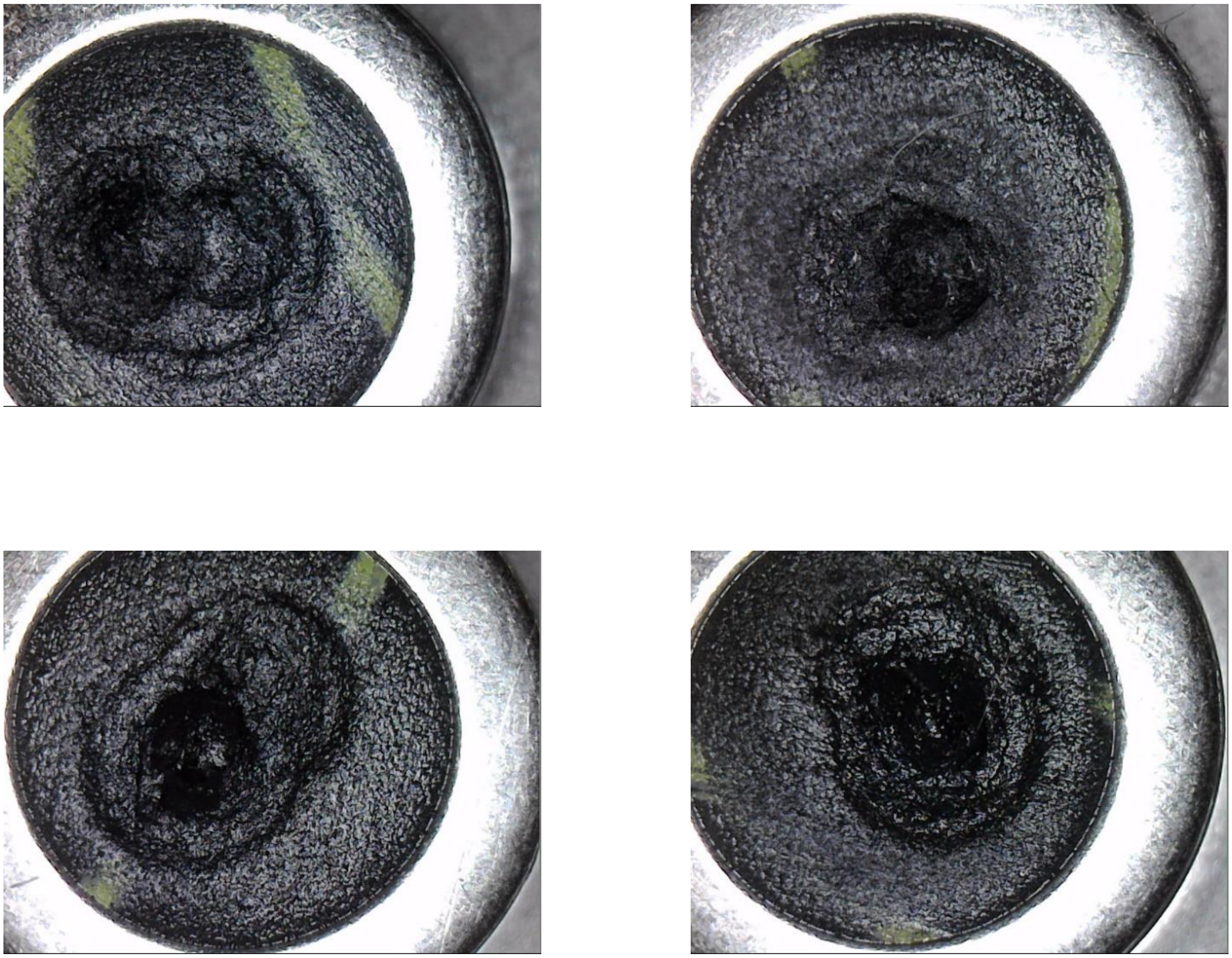


Figure 7: Diaphragm seats from four other pumps that cycled 500,000 times with B100

A general progression of diaphragm seat damage is shown below on pump 5, which operated on B5 fuel.

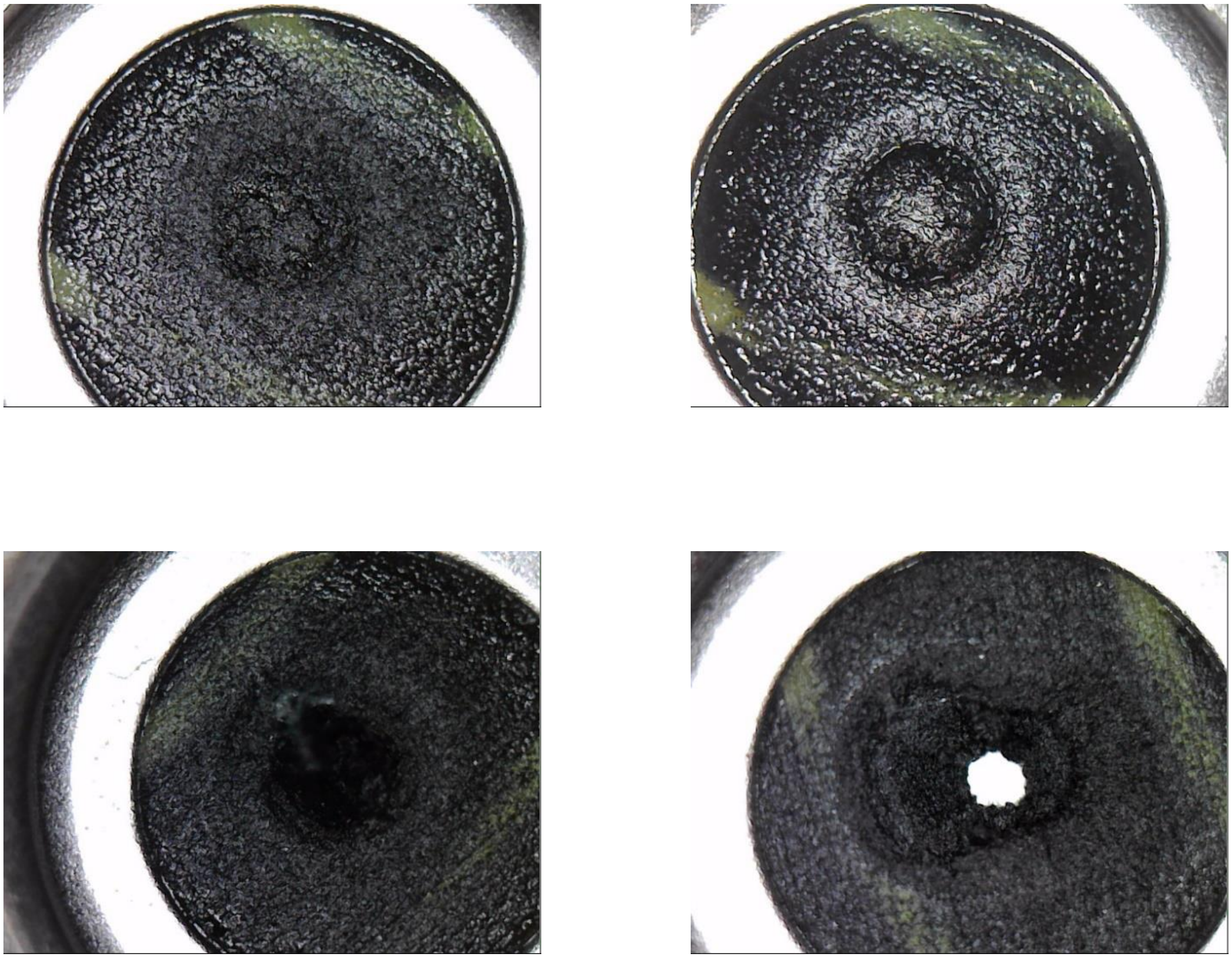


Figure 8: Progression of wear and tear in Pump 5 - 100,000 cycles (top-left), 200,000 cycles (top-right), 350,000 cycles (bottom-left) and 500,000 cycles (bottom-right)

Discussion

The cutoff time for each pump was generally expected to increase because of wear and tear as the number of cycles increased. This was not the case for the results obtained for any of the tested pumps. For example, even though the cutoff time increased for pump 15 from 100,000 cycles to 200,000 cycles, it was lower at 350,000 cycles. There is also no obvious sign that cutoff times increased with higher biodiesel blends. This can be better illustrated by the average cutoff times for each set of 8 pumps at every stop, as shown below:

Table 2: Average cutoff times at the scheduled stops

	Average Cutoff Times			
Fuel↓ - Cycles→	100,000	200,000	350,000	500,000
B5	0.3	0.28	0.34	0.23
B20	0.26	0.21	0.28	0.31
B50	0.28	0.21	0.23	0.19
B100	0.31	0.34	0.28	0.3

Comparing the average cutoff times across each row (i.e. same fuel, increasing cycles) provides no discernable pattern. The same is true when comparing values down each column (i.e. increasing biodiesel blend after the same number of cycles).

The worst-case scenario pictures of the piston faces show more damage to those belonging to pumps that were tested with B5 and B100, while those tested with B20 and B50 have no damage that is worth of note. For this reason, piston faces from the B5 and B100 groups were examined further. From *Figures 3* and *4*, it is evident that the damages seen in the pistons from the respective groups in *Figure 1* are not persistent but are most likely to have been exceptions. Furthermore, all piston faces from the B20 and B50 group not shown in *Figure 1* display no more than the normal wear and tear seen in those in *Figures 3* and *4* (refer to Appendix B).

The worst-case scenario pictures of the diaphragm seat show considerable amount of damage. After a prolonged period of exposure to fuel and contact under pressure with the diaphragm, some of the elastomer material deteriorated. It was known prior to the test that this deterioration eventually leads to a through-hole in the seat material, which was the case for the samples shown from the B5 and B50 groups. Only one other diaphragm seat has shown this level of damage, which belonged to the B50 group. In previous tests, damage of this sort has caused failure to produce pressurized discharge from the pump despite being able to draw fuel from the reservoir, which was not seen in this test. Further operation, however, would most likely have led the pumps with torn diaphragm seats to reach this failure mode rapidly.

The diaphragm seats shown in *Figures 6* and *7* did not contain any tearing of the elastomer material. However, the hole in the "seating" position of the diaphragm valve generally appears to grow over time. A perfect example of this is shown in *Figure 8*, where the hole eventually extends through the elastomer material. As noted earlier, only two other diaphragm seats showed wear and tear to such an extent. All the diaphragm seats for pumps in the B20 and B50 groups that are not shown in *Figure 5* contain the holes seen in those shown in *Figures 6* and *7* (refer to Appendix C).

There was one failure in the entirety of the test, which was suspected to be a failure of the diaphragm seat which, after performing a vacuum test, was determined to be a shaft seal leak. This pump was part of the B5 group and was then replaced by another pump, which completed 500,000 cycles.

Conclusions

Based on conservative estimates, an average pump in the field goes through ~10,000 cycles a year. According to that metric, all pumps that completed this test simulated ~50 years of operation in the field. The cutoff times obtained after testing at intervals show little to no effect as number of cycles increased. Increasing blends of biodiesel after any period of time also did not have any effect on the cutoff time for any of the pumps tested. Some components of the pump, however, did show some wear and tear, including the elastomers on the piston face and diaphragm seat. In the extreme cases, the damage in the seat elastomer formed a through-hole, which would lead to failure upon further cycling. There was, however, no indication that use of higher biodiesel blends caused such damage. It could then be concluded that use of higher biodiesel blends for prolonged periods of time with legacy Suntec A2VA-7116 pumps should not cause issues related to the components and properties that were examined.

Appendix A: Degradation of Fuels Over Time

Table 3: Induction times of fuels before and after 7 days of cycling on the test stand

Fuel	Induction Times (hours)	
	Before cycling	After cycling 7 days (~60,000 cycles)
B5	27.15	9.74
B20	15.48	2.23
B50	12.00	3.78
B100	11.77	7.23

Table 4: Acid times of fuels before and after 7 days of cycling on the test stand

Fuel	Acid Number (mg KOH/g	
	Before cycling	After cycling 7 days (~60,000 cycles)
B5	0.025	0.042
B20	0.039	0.159
B50	Not available	Not available
B100	0.131	0.171

Appendix B: Pictures of Piston Faces

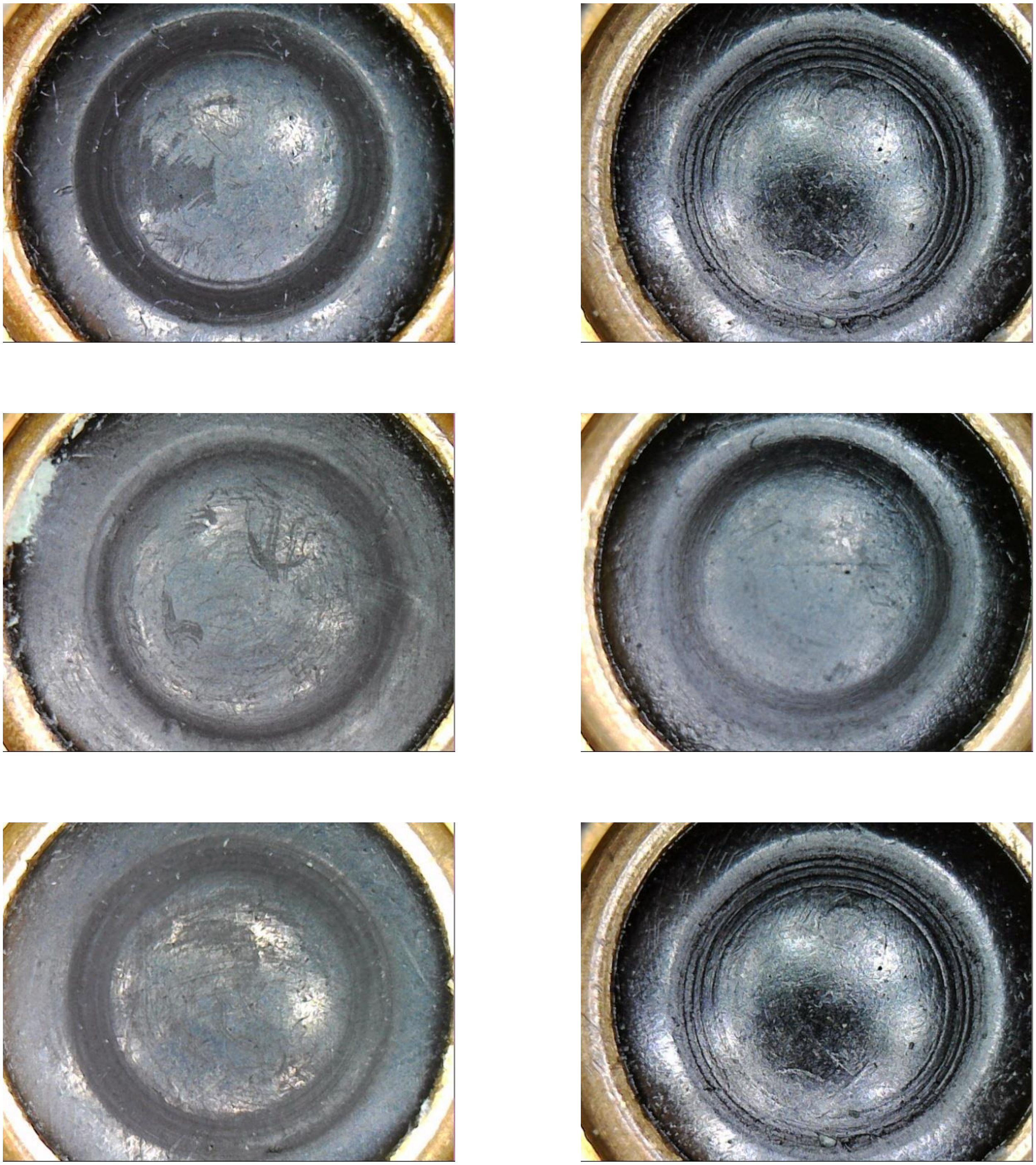
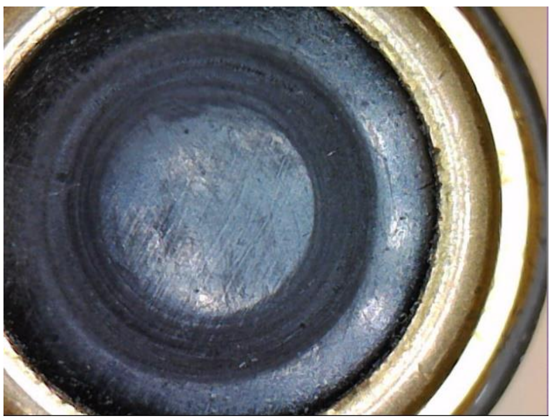
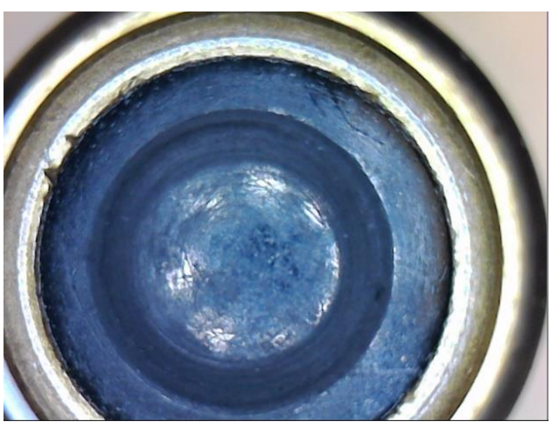
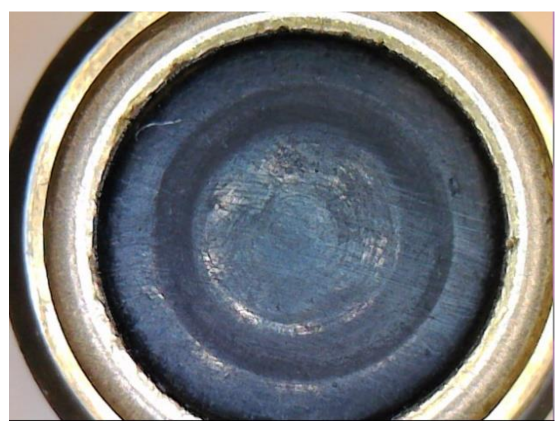


Figure 9: Piston faces of all pumps in the B20 group except pumps 17 and 23 after 500,000 cycles





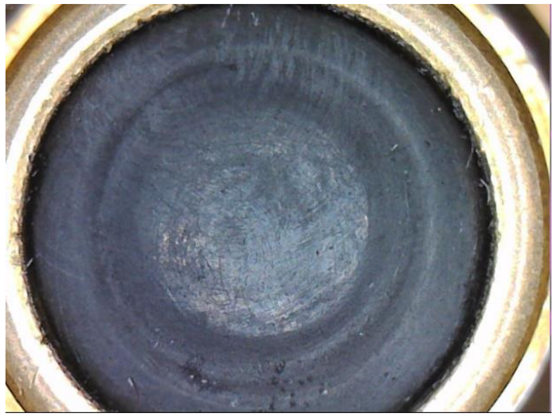
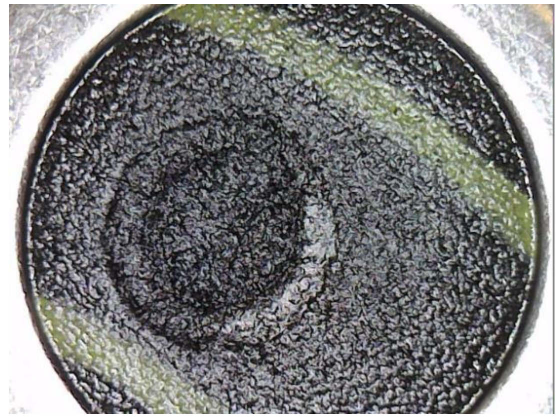
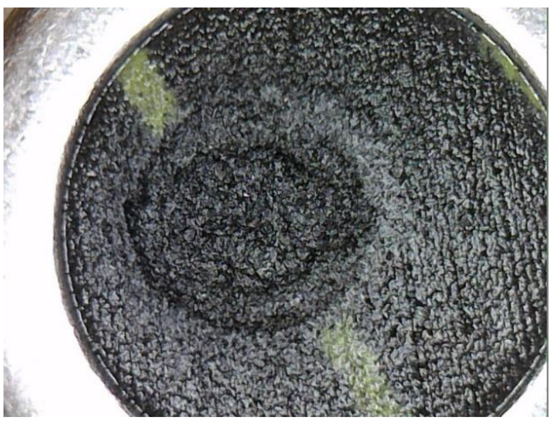
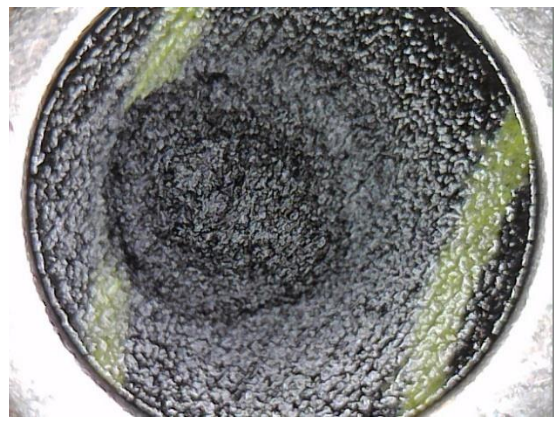
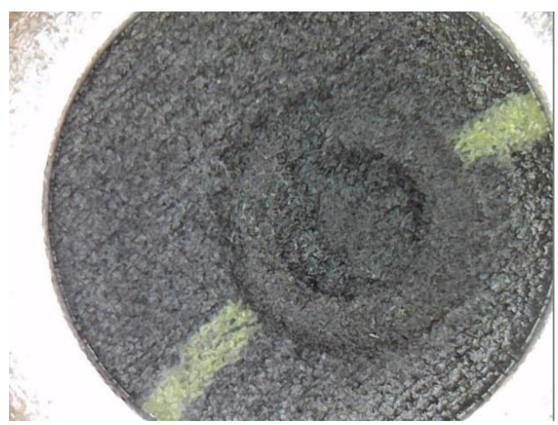


Figure 10: Piston faces of all pumps in the B50 group except pump 30 after 500,000 cycles

Appendix C: Pictures of Diaphragm Seats



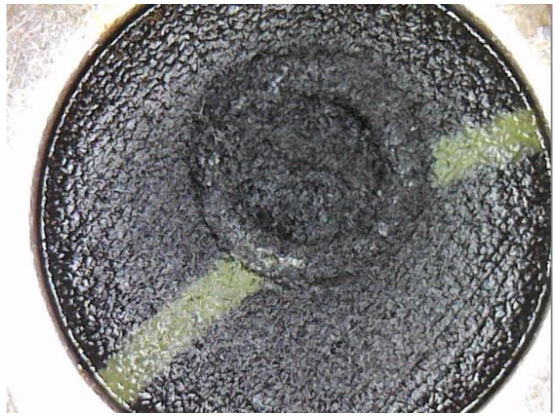
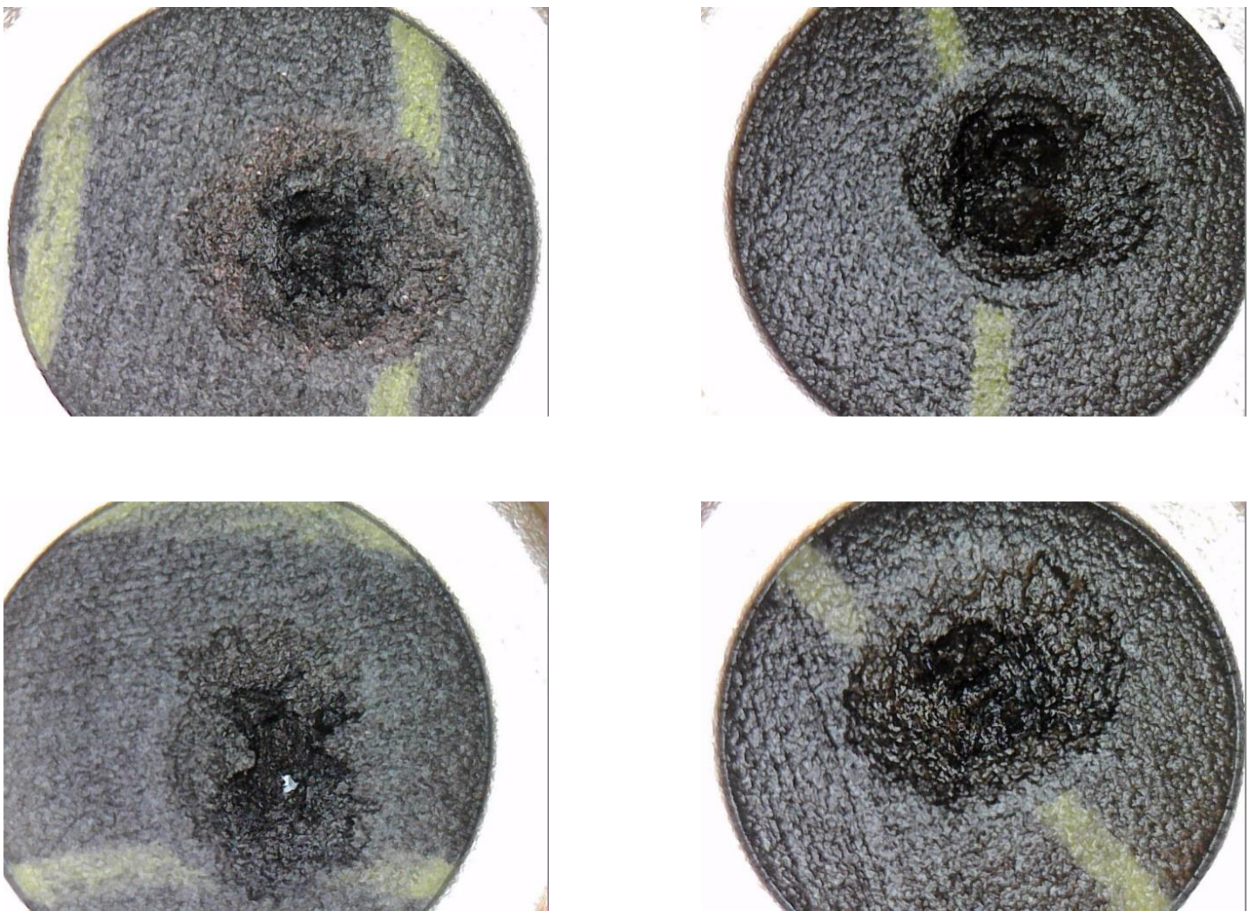


Figure 11: Diaphragm seats of all pumps in the B20 group except pump 18 after 500,000 cycles



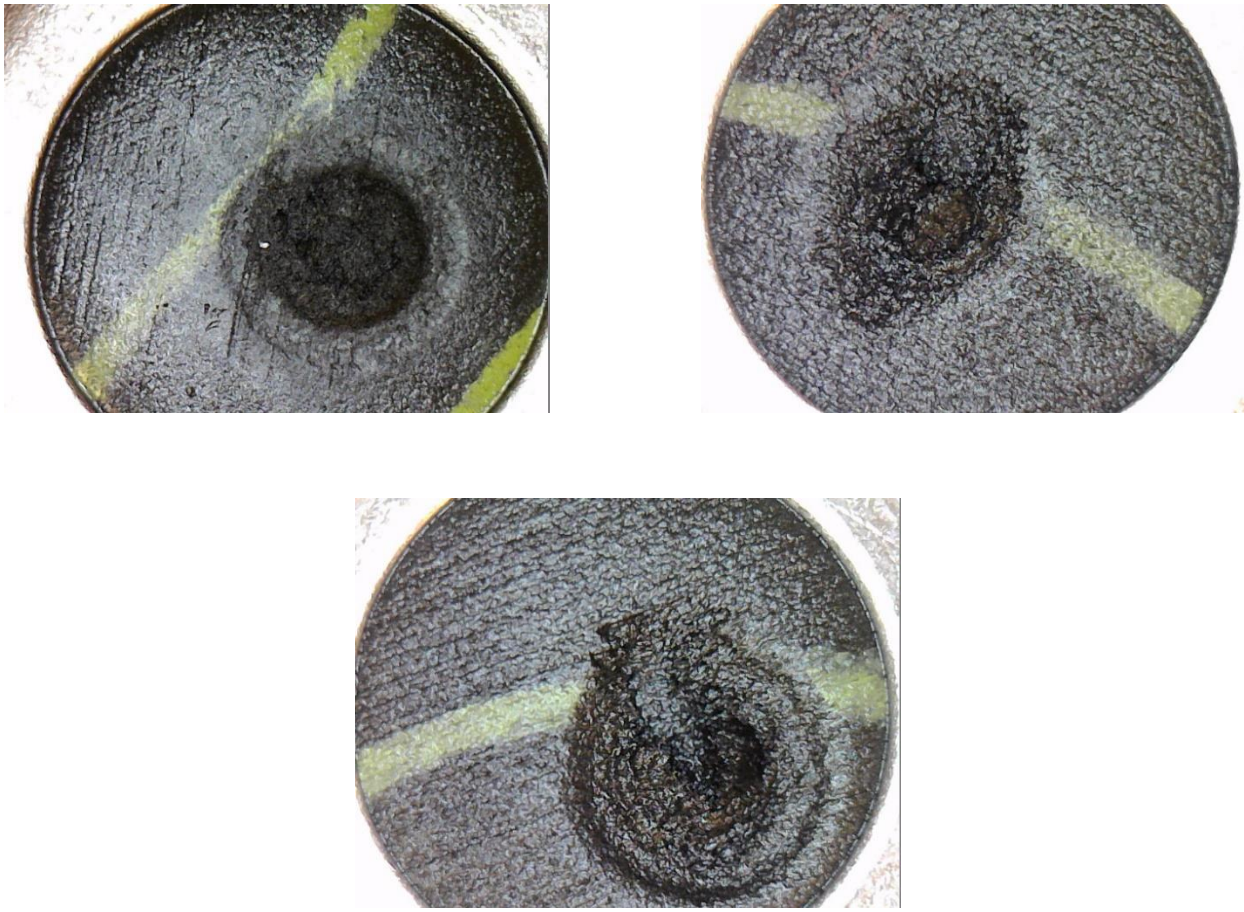


Figure 12: Diaphragm seats of all pumps in the B50 group except pump 27 after 500,000 cycles