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# THE EFFECT OF COMPRESSOR WASH ON GAS TURBINE TEMPERATURE OF TURBOFAN ENGINE

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## Abstract

In this study, the impact of compressor washing on improving the performance and engine life of a turbofan engine is analyzed. The purpose of this research is to determine the outcomes resulting from the compressor wash treatment, as well as the patterns and characteristics of engine deterioration rates in each block cycle following the wash. It also aims to identify the optimal timing for conducting a compressor wash to achieve the most favorable results and maximize the on-wing life of the engine. This research was conducted using an analytical method, which involved analyzing the data received from the Aircraft Communications Addressing and Reporting System (ACARS) to assess the influence of engine performance and deterioration characteristics on the conducted compressor wash. One set of temperature margin data analyzed reveals the benefits of washing in terms of the turbine gas temperature (TGT) margin. It shows a 7°C increase in the TGT margin, indicating improved performance, but a 3.1°C decrease in the unrecoverable margin. Furthermore, the analysis of the margin data per 100 cycles indicates that the rate of deterioration is steeper during the initial 300 cycles compared to the subsequent cycles. Based on these findings, it is recommended to conduct the compressor washing process at around 300 cycles to maximize engine life and achieve enhanced efficiency.

***Keywords***: *Trace Metal, $FeCl_3$, Biogas, High Organic Load*

## 1. INTRODUCTION

Modern aircraft have shifted to using gas turbine engines as their primary source of power. mainly because gas turbine engines offer several advantages compared to piston engines or traditional jet engines. One of the main reasons for using gas turbines in aircraft is their ability to generate high power in relation to their weight and dimensions. Gas turbines are designed to produce mechanical energy through fuel combustion and air compression. These engines have a high power-to-weight ratio, enabling aircraft to achieve high cruising speeds and efficiently carry larger payloads. Additionally, gas turbines have high thermal efficiency. Thermal efficiency refers to a machine's ability to convert heat energy into mechanical energy efficiently. Gas turbines can convert a significant amount of heat energy into useful power, with minimal energy wasted as heat waste. High thermal efficiency means that aircraft can use fuel more efficiently, reducing fuel consumption and emissions.

During operation, all components of a gas turbine engine, such as the compressor, turbine, and combustion chamber, undergo deterioration caused by various factors. This performance deterioration significantly impacts the decrease in generated power and the increase in fuel consumption. Consequently, it leads to higher operational costs and emissions. These two factors can contribute to increased maintenance expenses, making it

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imperative to maintain the highest efficiency of gas turbines [1][2]. The extent of performance deterioration varies for each engine, depending on the level of contaminants and the effectiveness of the compressor washing program used [1] [2][3].

Aircraft engine maintenance is a highly complex process, involving regular monitoring of engine conditions, maintenance tasks, and repairs[10] [11][12]. In the realm of gas turbine monitoring, several critical parameters require attention, such as TGT (Gas Turbine Temperature), fuel flow, vibration, oil consumption, and rotor speed (n). These main parameters serve as indicators of the engine's condition [4][5]. Degradation in these parameter values often necessitates engine repairs, and in some cases, the engine may need to be removed and repaired at an engine shop, commonly known as a shop visit [13] [15].

The on-wing life of an engine is greatly influenced by its thrust rating, operation factors (average legs per day, take-off derate, environment), and the age of the engine itself. A gas turbine consists of a compressor, combustion chamber, and turbine that work by rotating and drawing in air from the front and directing it with higher velocity towards the rear, similar to the flow over an airplane wing. As a result, the compressor section experiences a decrease in performance due to factors such as friction and the accumulation of contaminants from the air it ingests [3][5][6] [7][8].

Compressor wash is the process of cleaning the compressor in a turbofan engine. In a turbofan engine, the compressor is responsible for compressing air before it enters the combustion chamber. Due to the high volume of air flow, the compressor can accumulate dirt, dust, oil, salt, and other particles present in the air or encountered during flight [14][16][17]. By cleaning this component, it is expected to have a positive effect on the engine [17] [18][19] [20].

For the engine in this study, compressor wash is typically performed every 500 cycles to maintain engine performance, as evidenced by improvements in parameters such as TGT and N3 margins. It also helps reduce fuel costs resulting from decreased compressor efficiency due to the ingestion and buildup of contaminants during aircraft operation. By keeping the compressor clean and optimized, the compressor wash process helps maintain efficient performance and can increase the lifespan and reliability of turbofan engines on aircraft [21][22][23]. The purpose of this journal is to study and analyze the impact of compressor washing on turbofan engine and to find the best time to perform it based on real engine data. Because the engine operates on all kind of situation and condition, it’s better to study the engine based from its real data to understand it better.

Therefore, this research is necessary to investigate the impact of compressor wash on the rate of deterioration, as well as the characterization of deterioration in turbofan engines. This will allow for determining the optimal timing for compressor wash to achieve maximum on-wing life and minimal fuel burn.

## 2. MATERIALS AND METHODS

### 2.1. Experimental apparatus

This research is conducted using an analytical method, specifically by analysing data obtained from the Aircraft Communications Addressing and Reporting System (ACARS) taken from Airbus A330 operated by Garuda Indonesia with the help of Rolls-Royce web interface at GMF aeroAsia. The engine serial number is 42636. The data processing steps involve creating and comparing graphs of turbine gas temperature against the number of cycles for each block, and calculating the average decline values over time using Excel. The differences in each variation are analysed to determine the influence and characteristics of the Compressor wash on the observed parameters. This analysis enables us to understand the impact of engine performance and deterioration characteristics on the effectiveness of the Compressor Wash process.

### 2.2. ACARS

ACARS (Aircraft Communications Addressing and Reporting System) is a communication system used in A330 aircraft and other aircraft to send and receive digital text messages between the aircraft and ground stations. This system can utilize VHF (Very High Frequency) radio technology, HF (High Frequency), or SAATCOM (satellite communication) to transfer data. The system enables aircraft to send and receive various types of messages, including text messages, engine data, aircraft measurements, maintenance requests, and system error reports. These messages can be sent in real time or scheduled to be sent when the aircraft lands.

The ACARS system functions as an efficient and secure means of communication between aircraft and ground stations. Through ACARS, aircraft can send operational reports, submit maintenance requests, receive instructions from air traffic controllers, and obtain current weather information. The use of ACARS also allows aircraft operators and ground personnel to monitor aircraft performance in real time, obtain necessary data for aircraft maintenance and upkeep, and facilitate efficient and rapid communication between aircraft and operational control centers. The system can automatically transmit text messages and data electronically, replacing traditional voice communication that requires human interaction. This helps reduce human errors and improve operational efficiency.

Overall, ACARS is an important communication system that facilitates the exchange of information between aircraft and ground stations, contributing to more efficient operations, timely maintenance, and improved flight safety.

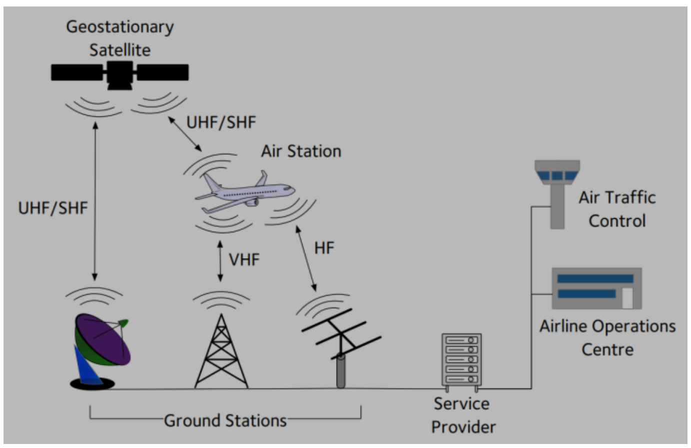


**Figure 1.** ACARS

### 2.3. EHM

EHM (Engine Health Monitoring) is a system used by Rolls-Royce to monitor the health and performance of its aircraft engines. EHM is designed to record important engine parameters and detect potential faults or issues in the engine at an early stage, allowing for appropriate maintenance actions to be taken before the problem develops into something more serious.

In EHM, Rolls-Royce utilizes various sensors and monitoring devices installed on the aircraft engine to collect operational data and engine performance parameters. This data is then transmitted via ACARS to the Rolls-Royce monitoring center equipped with advanced analytical software.

The Rolls-Royce EHM software analyzes the collected data to identify abnormal patterns or changes in engine performance. By comparing the data with developed reference models, the EHM system can provide early indications of potential issues, such as excessive wear on engine components, abnormal temperature changes, or fuel efficiency degradation. The information obtained from EHM can be used to analyze and determine the appropriate type of maintenance for the observed engine.

The sensor used in reading the TGT termperature data located at the inlet of Low Pressure Turbine. It's a thermocouple that generate an electrical voltage proportional to the temperature at thethermocouple. This indicating system uses 11 twin element thermocouple assemblies, located at equal distances around the engine within the Low Pressure 1 turbine nozzle guide vanes (LP1 NGV).

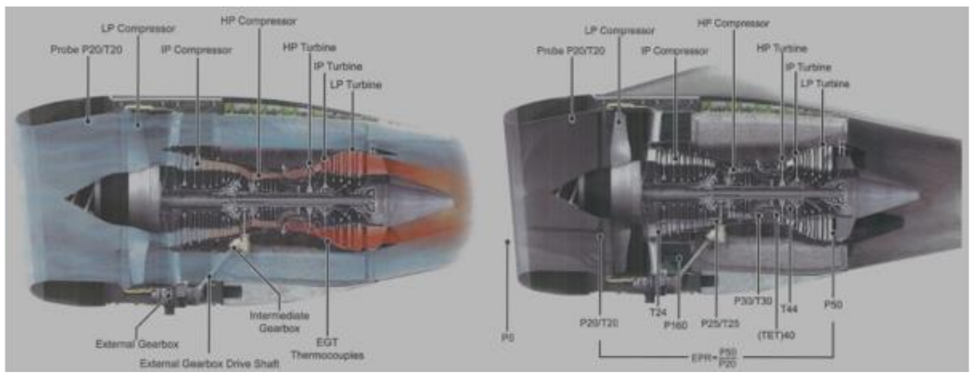


**Figure 2.** EGT or TGT Thermocouple location and its various sensors

The TGT is an indicator of the engine's current health as it increases with its age and level of deterioration. Engine manufacturers specify an engine specific upper TGT limit (EGTmax), which must not be exceeded. This temperature limit is usually defined by the material technology at the inlet of the High-Pressure Turbine (HPT), since this part of the engine will experience the most severe combination of high gas temperatures and high dynamic loads [4][7]. The difference between the peak EGT during take-off and EGTmax is defined as the Exhaust Gas Temperature margin (EGTM). The depletion of EGTM is often the dominant reason for an ESV[4][7][9] [18].

### 2.4. Diagram Method

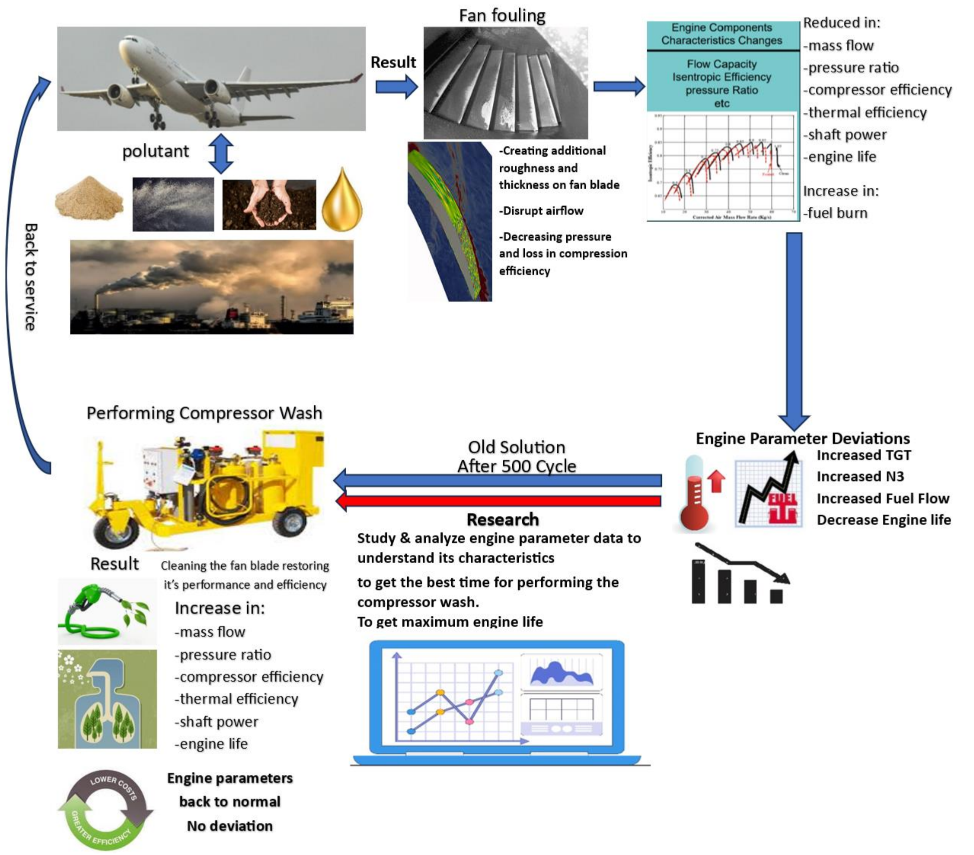


**Figure 3.** Conceptual Framework

The data taken from acars is analyzed and processed with Microsoft excel to create the chart, trend and calculated to better analyzed it. First, the data is grouped based on the compressor washing process, then the data from each group is converted into chart and create the trendline. to calculate the average recovery margin, the data from the last 10 cycle before compressor washing process is averaged and compared to the first 10 data after the compressor washing process. And to get the margin difference at 100 and 50 cycles, the trendline data at each block cycle is substracted to the next block cycle.

## 3. RESULTS AND DISCUSSION

Compressor washing process was carried out at around 500 cycles. There are 5 compressor washing process shown in the figure. And after each compressor washing process there is always an improvement in the engine's TGT margin. But the improvement never make the engine margin back to the initial value. This is means there are recoverable and unrecoverable degradation on the engine. The recoverable margin is due to compressor fouling and can be recovered with compressor washing process. And from one of this compressor washing process there's a turbine gas temperature margin increase of 7.6166760C after 478 cycles.

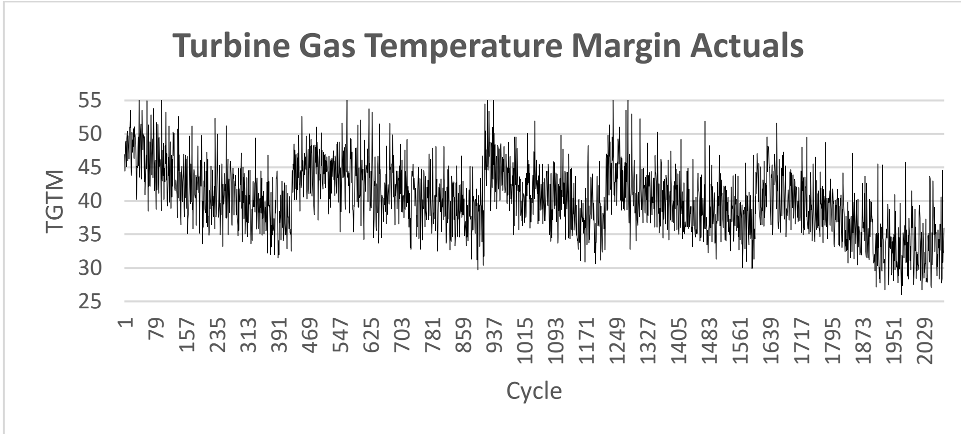


**Figure 4.** Temperature Gas Turbine Margin on 5 compressor washing process

Fig. 4 displays turbine gas temperature margin during a compressor washing process. There are five compressor washing processes represented on the x-axis labelled "Cycle." The y-axis shows the temperature margin in degrees Celsius (°C).

Based on the graph, the turbine gas temperature margin appears to fluctuate throughout the five compressor washing cycles. It's normal for the engine that works in all kind of situation and condition to fluctuate.

In general, a higher turbine gas temperature margin is better, as it indicates a larger safety cushion between the engine's actual operating temperature and the maximum safe temperature. And based on the graph after each compressor washing process there's an improvement in the margin but this improvement never makes the margin back to the initial condition. That means there are recoverable deterioration that can be rectified by compressor washing process and there are unrecoverable deterioration that can only be rectified by performing overhaul on the engine.

From a total of 2148 cycles and 5 compressor washing process, the first average TGTM was 47.59°C and after 2148 cycles the average TGTM dropped to 42.87°C. There are 4.72°C margin lost after 2148 cycles. This lost is called unrecoverable margin that can only recovered by performing shop visit or engine overhaul. This unrecoverable is due to increase gap and other factor [24][25][26].

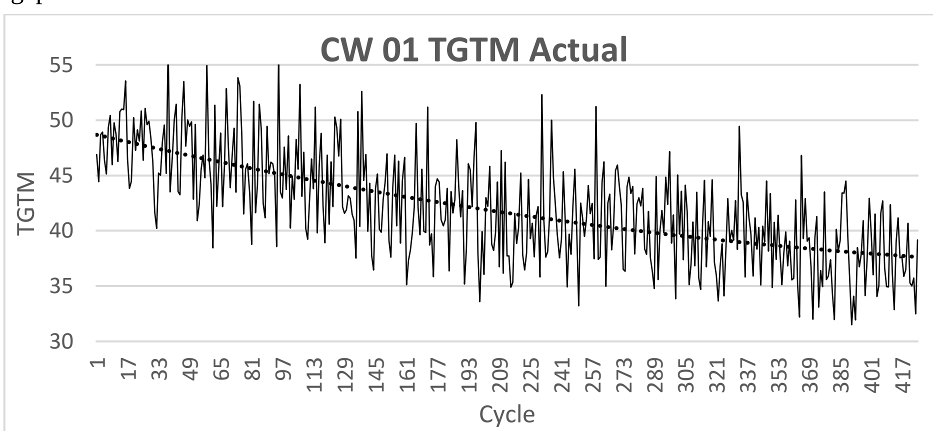


**Figure 5.** TGTM Actual on first Compressor Washing Process

Fig. 5 depicts the TGTM after the first compressor washing process. There are 421 cycles between the first and second compressor washing process. The TGTM margin fluctuates throughout the 421 cycles depicted in the graph and trending down. and at the first 200 cycles the TGTM going down rapidly and after that the trend begins to slope. It's consistent with previous analysis that Beyond a certain level of saturation, dust does not further accrue on the airfoil surface. (EXPERIMENTAL EVALUATION OF COMPRESSOR BLADE FOULING) Rainer Kurz.

For a total of 421 cycle after the first compressor wash there's a decline in the temperature margin. From the 10 cycles average of 47.59709 at first to 36.59259 at the last 10 cycles. Or 11.0045 drop at the TGT margin after 421 cycles. After the compressor washing process the margin back to 44.457172 or there are $7,77^0$C improvement in TGT margins. And there are $3.13^0$C unrecoverable deterioration between the 2 compressor washing process.

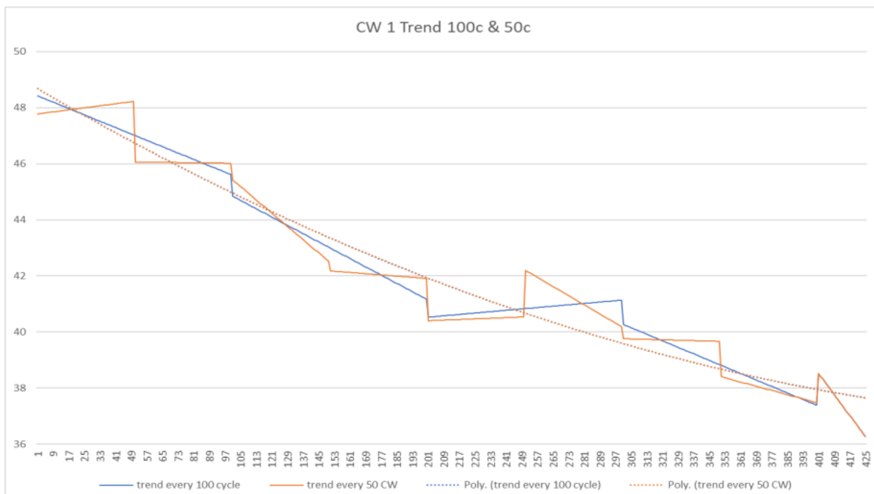


**Figure 6.** Trend margin data every 100 cycle and 50 cycle based on TGTM Actual

Figure 6 shows the TGTM actual trend at every 50 and 100 cycles comparatively and it's trendline. from the total of 421 cycles between compressor washing the data shows that the first 250 cycle the trend data is below the trendline and after the 250 marks the trend begin sloping and its above the trendline. it's indicating that the deterioration in this phase is slowing down.

| Cycle | Trend at 50c | Trend at 100c |
|---|---|---|
| 0 | 0 | 0 |
| 50 | 0.442820776 | -1.404432814 |
| 100 | -0.041830518 | -2.808865628 |
| 150 | -2.895437459 | -3.234158498 |
| 200 | -0.266084824 | -3.659451368 |
| 250 | 0.135910047 | -1.526409172 |
| 300 | -1.998554541 | 0.606633024 |
| 350 | -0.090878706 | -1.137245109 |
| 400 | -0.919872565 | -2.881123242 |
| 450 | -2.251554277 | -2.251554277 |

**Figure 7.** Delta Trend at 50 cycles and 100 cycles based on actual TGTM

Figure 7 shows the delta trend at 50 and 100 cycles respectively. it shows the highest delta occurs at the first 200 cycles and begin sloping at later cycles. On 50 cycle data, the highest delta recorded at -2.895 at 150 cycles. and on 100 cycles delta trend, the highest delta recorded at -3.659 at 200 cycles. it show's that after 200 cycles the delta begin to slope and consistent with other research that after certain amount of work, the contaminant begin to fulfil all the area and it's getting harder for new contaminant to settle.

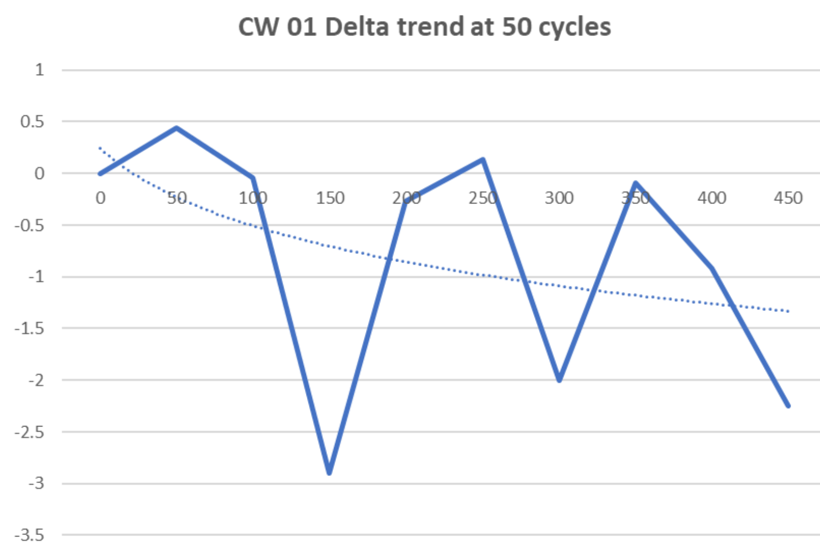


**Figure 8.** Delta Trend at 50 cycles

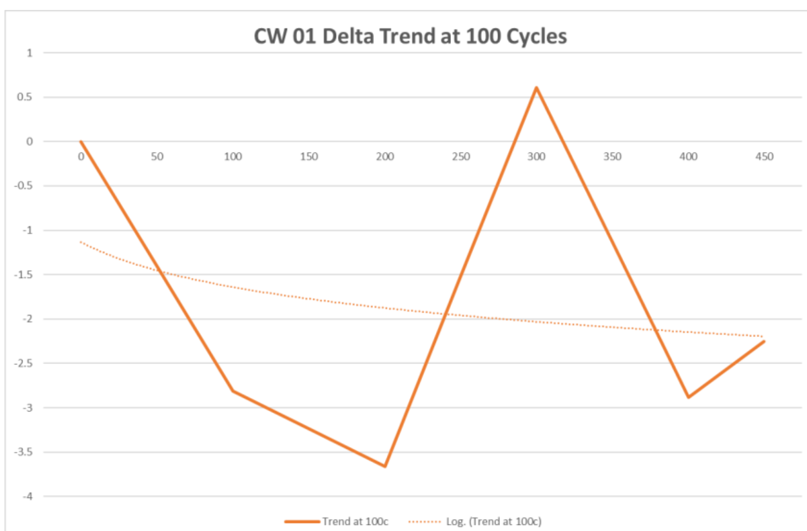


**Figure 9.** Delta Trend at 100 cycles.

Figure 8 and 9 shows clearer view about the delta trend at 50 and 100 cycles and it's trendline. its because at the first 200 cycle the engine tend be contaminated due to clean condition and after the 200 cycle the compressor section is already full of contaminant so it's getting harder for other contaminant to settle.

## 4. CONCLUSIONS

The compressor washing process affects the performance of the engine, decrease the workload and improve efficiency so that doing the compressor washing process can make the engine better in all aspects. The optimum time to perform compressor wash is around 250 to 300 cycles, where the margins already droping so low and are sloping that means the contaminant is already settle so much that it's harder for the new contaminant to settle and doing the process early can slow down the unrecoverable deterioration for better engine performance and efficiency. And the compressor washing process can improve the margin at around $7^0$C and there are $3.13^0$C unrecoverable deterioration at the 421 cycle.

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