ASME Paper Title: Comparative assessment of fouling scenarios in an axial flow compressor

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ASME Conf Title: ASME Turbo Expo 2020

Volume/Issue: __Volume 5 _____ Date of Publication (VOR* Online) 11 January 2021 _____

ASME Digital Collection URL: https://asmedigitalcollection.asme.org/GT/proceedings/GT2020/84140/Virtual,%20Online/1094859

DOI: https://doi.org/10.1115/GT2020-14393

Proceedings of the ASME 2020
Turbomachinery Technical Conference and Exposition
TURBO EXPO 2020
June 22-26, 2020, London, England

GT2020-14393

COMPARATIVE ASSESSMENT OF FOULING SCENARIOS IN AN AXIAL FLOW COMPRESSOR

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ABSTRACT

It is commonly accepted that fouling degrades severely axial compressor performance. Deposits build up through the compressor operating life, causing a decrease in the compressor's: delivery pressure, efficiency and flow capacity. Researchers have also concluded that the presence of wet contaminants and/or high air humidity and the quality of air filtration systems, have a far greater impact on fouling rates, than engine specific fouling susceptibility factors. The size of airborne particles ingested into the engine is primarily controlled by the presence of a filtration system. On the other hand, the particle deposition rate and the fouling patterns formed on the blade surfaces are greatly affected by the "stickiness" of the blade surfaces which in turn is affected by the moisture level of the incoming air. Compressor geometry, size and operating point would affect far less the rate of contaminants built up on the wetted surfaces and they would affect even less the exact location on compressor walls and blade surfaces. The current study identifies four basic operating scenarios which refer to the same compressor, in order to put forward a comparative assessment as to how the factors mentioned above affect the compressor performance through the fouling mechanism. Scenarios were formed out of the possible combinations regarding the presence of a filtration system and the level of humidity. These were: Filtered - humid air, filtered - dry air, unfiltered - humid air and unfiltered - dry air. These scenarios will eventually reproduce four completely different situations regarding the quality of the incoming air and subsequently, four different fouling regimes for the compressor operating downstream. Data to support the impact of each reported incoming air condition on compressor wetted surfaces, are based on experimental findings collected from a solid literature review A fixed operating period was set for all cases.

Prescribed requirements of the computational tool selected to build the compressor model were; i) low computational power since several runs have to be performed in order to cover the assumed time period and ii) ability to introduce the imprint of various fouling patterns on compressor blades, into the performance of the compressor. SOCRATES, an in-house two-dimensional, streamline curvature-based, through-flow computational tool, meets these requirements and it was therefore used for this study. A fully customizable empirical model recently introduced in the code, takes into account various aspects of fouling such as the surface roughness level, the flow blockage and the altered deviation angle at the exit of the blade row. A coverage factor was introduced which takes into account the location and the extent of fouling onto the blade surfaces.
Keywords: turbofan engine, fouling, Streamline Curvature

NOMENCLATURE

Place nomenclature section, if needed, here. Nomenclature should be given in a column, like this:

α	alpha
β	beta

1. INTRODUCTION

The starting point for the current research, was the basic conclusion drawn by Kurz et al. [1], that the presence of wet contaminants and/or high air humidity and the quality of air filtration systems, have a far greater impact on fouling rates, than engine specific fouling susceptibility factors. The size of airborne particles ingested into the engine is primarily controlled by the presence of a filtration system. On the other hand, the particle deposition rate and the fouling patterns formed on the blade surfaces are greatly affected by the "stickiness" of the blade surfaces which in turn is affected by the moisture level of the incoming air. Compressor geometry, size and operating point would affect far less the rate of contaminants built up on the wetted surfaces and they would affect even less the exact location on compressor walls and blade surfaces. Based on the above, four scenarios were examined in order to reveal the importance of these two principal fouling governing factors. Scenarios were formed out of the possible combinations regarding the presence of a filtration system and the level of humidity. These were: Filtered - humid air, filtered - dry air, unfiltered - humid air and unfiltered - dry air. These scenarios will eventually reproduce four completely different situations regarding the quality of the incoming air and subsequently, four different fouling regimes for the compressor operating downstream. A fixed operating period was set for all cases. In the absence of on-line washing installed on the compressor, this period was set equal to a typical time interval between two consecutive offline washes. Prescribed requirements of the computational tool selected to build the compressor model were; i) low computational power since several runs have to be performed in order to cover the assumed time period and ii) ability to introduce the imprint of various fouling patterns on compressor blades, into the performance of the compressor. SOCRATES, a two- dimensional, streamline curvature-based, through-flow computational tool meets this requirements. Moreover, a fully customizable empirical model was recently introduced in the code that takes into account various aspects of fouling such as the surface roughness level, the flow blockage and the altered deviation angle at the exit of the blade row [2]. The model was upgraded for the needs of the current study. A coverage factor was introduced which considers the location and the extent of fouling onto the blade surfaces. Otherwise, SOCRATES, being an inviscid flow solver, gives a converged flow solution for a certain operating point of a single stage compressor, in about one and a half minute on a standard desktop PC.

The manuscript is structured as follows: Firstly, a literature review is given, related to compressor fouling, and focusing in particular on the underlying mechanisms and simulation efforts done by researchers in the past. Then the simulation tool is presented along with the empirical fouling model update. Within the section that follows, the four fouling scenarios are thoroughly described and justified based on the criteria upon which their definition was based. Finally, before summarizing the basic findings and conclusions, the comparative results between the four scenarios are presented.

2. LITERATURE REVIEW

Compressor fouling, as an engine fault, refers to the performance degradation of the compressor caused by the deposits' built up on the wetted surfaces. Deposits affect the performance of the compressor because they; i) increase the surface roughness and ii) alter the gas path geometry. The aforementioned chargeable events will lead to compressor performance degradation. Schneider [3] in terms of specific performance parameters, tracks down a reduction in all isentropic efficiency, swallowing capacity and pressure ratio. The fact that deposits are to a certain extend removable, put compressor washing, in the center of interest for many researchers and users. There is a lot of relevant published research. Boyce et al. [4] conducted a series of onsite tests on several installed gas turbine engines, as part of their effort to define an optimum, universal washing schedule. They concluded that an optimum washing schedule does exist, but it will not be universal as it depends among others, on the site location. Brun et al. [5] gives a good literature review on similar attempts to optimize a combination of offline and online washing schedules. Aretakis et al. [6] for instance coupled an economic model along with their engine performance model and explored the impact of several factors on the formation of an optimal washing schedule. Stalder et al. [7] revealed the importance of humidity content of the incoming air on the fouling process. He noticed, based on onsite measurements that the power loss maximizes at a certain value of total absolute humidity. The power loss increases while the water content functions as a sticking agent for the contaminants and decreases when the water content surpasses a limiting value functioning as a washing medium for the compressor. There have also been several studies addressing the type and extent of fouling occurring based on the engine size [8], the particle size [9] and the composition of incoming air contaminants [10]. The later researchers looked, in particular, at the impact of compressor fouling caused when there is high sea water content in the stream of the incoming air. A good summary of particle entrainment and deposition mechanisms is given in [11]. Finally, as far as the impact of fouling on compressor performance and the entire engine is concerned, the reader can find several references in the open literature. Aker et al. [12] and Diakunchak et al. [13] were among the pioneers in this field. Otherwise Meher-Homji et al. [14] provided a good summary of relevant work.

3. SIMULATION TOOL

The four fouling scenarios were reproduced using a compressor model build in SOCRATES, a Cranfield University in-house through-flow simulation tool. The tool was first introduced in 2007 [15]. It is based on a through-flow method (Streamline Curvature). There are several publications, focusing on different aspects of the code such as an innovative loss model adaptation technique [16], integration with 0-D tools [17], [18] and lately a thorough study on the importance of the force terms modelling in the radial equilibrium equation [19].

The calculation procedure that the simulation tool follows, is described in great detail in [18]. The numerical solver is based on four nested loops which are, starting from the inner:

i. Determination of the static temperature given the total temperature, the specific heat capacity under constant pressure, and the flow velocity (based on total values, specific heat capacity under constant pressure and flow velocity),

ii. Determination of meridional velocity profiles along the quasi radial stations,

iii. Calculation of mass flow for each streamtube based on local values determined during the previous steps, and

iv. Calculation of the total mass flow by summing up streamtube mass flows,

v. Determination of the overall compressor annulus mass flow or outlet static pressure.

The fidelity level of the flow solution is mainly dependent upon the set of phenomelogical models incorporated in the solution code, which are there to account for the flow viscosity related effects. The inviscid component of the flow for the geometry used in the current study was tested using the experimental set of values for the loss factors (profile and loss), blockage factors and deviation angles [2]. In [19], the same validation study was conducted, on a similar geometry [32]. Both studies confirmed that the inviscid flow component is calculated correctly and also that all the "side effects" caused by entropy generation, are correctly accounted for, through the introduction of appropriate fictitious forces [19].

4. EMPIRICAL MODEL

In [2] a thorough description is given of a novel fouling loss model which was conceived in order to address the effect of compressor fouling on the induced profile loses, flow blockage and deviation angle. The model was validated against the high fidelity, CFD numerical results obtained by Morini et al. [20]. This comparison showed that the model is capturing correctly the qualitative trends across the operating mass flow range tested, a fact that makes it appropriate to be used for comparative studies like the one presented in the current manuscript. The initial version of the fouling model did not take into account the degree of coverage and the location of the deposits on the blade surfaces. In the paragraphs that follow, each component of the empirical model is presented in brief, along with the modifications which account for their new, "variable coverage" characteristic.

4.1 Profile Loss Model

The model which accounts for profile losses [2] is based on a Moodi's type of diagram as defined by Koch and Smith [21] with some modifications in order to incorporate the dependence of profile losses on surface roughness increase caused by the blade deposits, at various Reynolds number levels. The model was built based on relevant experimental work done by Morini [20]. The model was defined on the principle that the total profile loss consists of two components: the basic profile loss and the fouling profile loss corresponding to the clean and fouled blade performance respectively (equation 1). Each of these components is further split into their corresponding minimum profile loss and off-design loss subcomponents (equations 2 and 3). The minimum profile loss occurs at the minimum loss incidence conditions. Any other incidence angle setting, will cause additional profile loss for the flow, which is accounted by the off-design profile loss components.

Seung et al [22] conducted a systematic experimental work to investigate, among others, the impact of deposit location on the compressor performance. The aforementioned fouling profile loss model was modified accordingly, based on these experimental results, in order to take into account the degree of coverage and the location of the deposits. A coverage factor was defined which practically interprets the loss versus Reynolds number curves shown in figure 13 of [22]. The existing fouling loss model corresponds to the full roughened case. It can be seen that for the case of roughened pressure side and a roughened leading edge the profile loss has very little dependency on Reynolds number. Also for the case where the suction side is covered with fouling deposits up to 20%, the profile loss still has no dependence on Reynolds number. Therefore the coverage factor needs to address the dependence of the profile loss on the Reynolds number for various deposit locations around the blade surfaces only in the case where fouling exists on the suction side at a coverage percentage between 20% and 100%. These refer to a certain incidence angle and therefore the effect of blade coverage is taken into account for the calculation of the minimum profile loss factor. In other words, it is considered that the entire pressure loss vs. incidence angle curve is shifted without a change occurring on its shape. Based on the proposed profile loss model the total profile loss factor comes as a sum of the basic profile loss component which refers to the clean blade surface and the fouling related component. Each of these is further decomposed into their corresponding minimum loss and off-design component:

$$\omega_{p,total} = \omega_{p,basic} + \omega_{p,fouling} \tag{1}$$

where

$$\omega_{p,basic} = \omega_{p,basic,ml} + \omega_{p,basic} \tag{2}$$

$$\omega_{p,fouling} = \omega_{p,fouling,ml} + \omega_{p,fouling} \tag{3}$$

The first term in equation 1, the basic profile loss component, is calculated as described in [23]. The method is presented also in [2]. The second term of the same equation which expresses flow irreversibilities due to fouling, is determined based on the Reynolds number level and the relative surface roughness increase caused by the blade deposits. The minimum loss component in equation 3, is determined for the case where the blade is fully covered with deposits resulting in a uniform surface roughness increase at every blade location. Therefore minimum fouling profile loss factor values, as defined above, correspond to the 100% roughened blade. Consequently the coverage factor shall be defined in a way to reduce the fouling minimum profile loss factor, for any other case where the blade is not fully covered with deposits. Based on the above, equation (4) gives the minimum fouling profile factor taking also into account the degree of coverage:

$$\omega_{p,fouling,ml} = CF * \omega_{p,fouling,ml} \tag{4}$$

where CF takes values between 0 and 1 and equals to zero when the extent of fouling does not affect the profile losses. It is clarified that the off-design fouling loss component will also be equal to zero, since it is determined based on its corresponding minimum loss value.

4.2 Deviation Model

It is generally accepted that deviation angle increases with increasing surface roughness [24], [25], [26]. The current fouling loss model as far as the deviation angle change is concerned, adopts the same method as reported in [24]. The results refer to 100% covered blade surface. Based on the literature search conducted by the authors, there were no publically available experimental or even computational results on the effect of the fouling location on the deviation angle change. . However, according to the static pressure distributions shown in figure 10 of [22], -the static pressure distribution curves correspond to the loss vs Reynolds number curves that were used to define the coverage factor in section 4.1- the static pressure coefficient changes considerably only for the cases of 100% "suction side roughened blade" and "entirely roughened blade". Static pressure distribution around the airfoil gives an indication of the blade loading and at a constant incidence angle a change in blade loading can only come from a change in the deviation angle. Therefore the approach adopted for this study was that the deviation angle component due to fouling will only be considered in the cases where at least 100% of the suction surface is covered with fouling deposits.

4.3 Blockage

The existing fouling model considers that additional flow blockage is introduced to the flow, through both the thickening of the blade profile and the thickening of the boundary layer. Regarding the first, direct mechanism of flow restriction, the current version of the through-flow computational tool used, would only "sense" a change in the blade profile shape through the change in the cascade throat area. Since the geometry and the fouling pattern are fully defined in the input file, in terms of location and deposit's layer thickness, no further changes were necessary for the geometrical calculations.

For the second, indirect blockage mechanism, the boundary layer thickening induced blockage, the existing model is based on the calculated total profile loss factor. A value for the equivalent diffusion factor is determined for a certain profile loss factor value, which is then used to determine the blockage factor value. Consequently, as in the case of geometrical changes, the current model adopts without further modifications, the effect of fouling location on the induced blockage.

5. SCENARIO DEFINITION

Compressor fouling is a process controlled by many factors. It depends on the condition of the incoming air, the design of the engine in general and the compressor in particular, and the engine operating point. It is therefore highly improbable and it has not been done yet, to establish a universally applicable methodology, based on which one could predict the exact fouling pattern and subsequently the effect of this pattern on compressor performance. However there have been numerous attempts, as it was also mentioned in the introduction, to predict the rate and the degree of fouling taking into account the above mentioned factors. In the current study, authors defined operating scenarios, applied on the same compressor, in order to reveal the effect of the filtration system and the moisture of the incoming air, onto the compressor performance. Specifically four scenarios were defined: i) Dry filtered air, ii) Wet filtered air, iii) Dry unfiltered air, iv) Wet unfiltered air. The expected compressor fouling condition, assumed and described later on in this section, for each fouling scenario, was based on the following remarks:

i. The presence of a filter in the incoming air, blocks a certain percentage of the higher diameter airborne particles. The limiting, smallest particle diameter that the filter blocks, depends obviously on the type of filter.

ii. The higher the particle diameter the easier for it to deviate from the streamline path and follow its inertial trajectory. On the other hand, smaller particles abide to the diffusion, as it is called, contamination mechanisms. These follow in general the streamline path and they tend to end up on the suction surface of the blade, especially in areas of high turbulence intensity.

iii. Based on remarks by Kurz [1], most particles would reach the pressure surface of a blade rather than the suction, through inertial impact. Collection efficiency for inertial impaction, maximizes for high particle diameter.

iv. The presence of moisture and the nature of the particles will primarily affect the built up rate of the contaminants.

v. Experiments carried out by Seug [22], have shown that fouling implications on compressor performance aggravate when the suction surface, as compared to the pressure surface, is fouled.

When a filter is installed in the intake, only the smaller diameter particles will be let into the compressor. These particles according to point (ii), when entrained by the air, will follow the streamline paths closely and they will most probably depose on the suction surface of the blades and in particular in areas of high turbulence intensity. Consequently, the compressor blades, in the case of the first scenario, are expected to operate with a percentage of their suction surface covered with deposits. In the case where the air is humid, (2nd scenario) particles will in general still be entrained along the streamline paths and deposits will appear in the same locations, at a higher built up rate. On the other hand, when the compressor is breathing dry atmospheric air unfiltered, the entrainment mechanism, which refers to the small particles as described in the first scenario, will be present, but according to points II and III, the pressure surface of the blade will also be covered with dirt. In other words, the third scenario will result in fully fouled blades. Finally in the case of the forth scenario according to which the air has a high humidity content, or the particles are of sticky nature, the blades will be, covered with dirt faster than the third scenario.

The axial flow fan "NASA Stage 37" was selected for the assessment of the proposed case studies. Design and performance data can be found in [27]. It is a single stage axial fan fitted with an inlet and exhaust duct. The rotor has 36 blades, of MCA profile, characterized by an inlet hub to tip diameter ratio of 0.7, a blade aspect ratio of 1.19 and a tip solidity of 1.29. The stator has 46 blades with an aspect ratio of 1.26 and a tip solidity of 1.3. The stage performance is summarized in table 1.

Table 1
Single-stage fan design point performance.[27]

Pressure Ratio	2.05
Isentropic Efficiency	0.84
Mass Flow (kg/sec)	20. 2
Rotor Tip Speed (m/s)	454

TABLE 1: Single-stage fan design point performance.[27]

The aforementioned geometry was selected by the research team to demonstrate the validity of their model, for the following reasons:

a) A single stage geometry is sufficient to conduct a comparative study between the four scenarios.

b) The same geometry was used by the authors to test the validity of the underlying set of fouling loss models. Given the fact that there are no relevant data to validate directly the proposed fouling scenarios, the current geometry presents a good starting point for such a study.

	Description	Coverage factor	Relative surface roughness vs time elapsed.				
			200 hours	400 hours	600 hours	800 hours	1000 hours
1st	Dry filtered air	0.6	0.809	1.38	1.87	2.29	2.63
2nd	Wet filtered air	0.6	1.3	2.43	3.57	4.71	5.85
3rd	Dry unfiltered air	1.0	0.809	1.38	1.87	2.29	2.63
4th	Wet unfiltered air	1.0	1.3	2.43	3.57	4.71	5.85

TABLE 2: Input Data for Fouling Scenarios.

The inputs for each scenario are summarized in table 2. Given the fact that the compressor is not linked to a gas turbine engine, its performance is quantified on the basis of total enthalpy rise. A typical TBO of 1000 hours was considered, split in five, two hundred hours-long operating periods. Input for the 1st scenario (Dry unfiltered air) was based on figure 9 of [28] where the equivalent sand grain roughness increase due to fouling depositions, is related to the number of operating hours, for Stage 37. In this study roughness was considered uniform along the entire surface of the rotor and the stator blades. This data was adopted because first they refer to the same geometry, and second, as it was explained above, in the case of unfiltered dry operation, blades are considered to get fully fouled, with progressively increasing roughness. In the case where a filter is installed, the blade is considered to be covered by 60% at all times, a percentage which roughly corresponds to the blade area percentage where high turbulence intensity exists. Based on Suman et al [29], deposits on the suction surface appear distributed on the whole blade surface. The same conditions were assumed along the entire blade span in this study. The rate of roughness increase vs. operating time was kept the same, since the filter will only block the higher diameter particles which are generally guided towards the pressure surface. The 2nd and 4th scenarios generally represent an operating environment where enhanced "sticking conditions" are present. This can be caused for instance by oil mist concentrations, high humidity air and also by the nature of the contaminants itself. The aforementioned conditions compared to the 1st and 3rd scenarios, will mainly affect the rate of deposition and much less the areas where contaminants are deposited. Empirical correlations derived from Vigueras [30] experimental work were used to determine the surface roughness increase rate for these two scenarios. Vigueras, in his axial compression stage test rig, examined the fouling behavior of the stage when blades are covered with a sticking agent. He measured and defined a series of empirical equations, regarding area specific surface roughness variation. An average surface roughness variation rate, based on these empirical equations, was adopted for the two remaining scenarios. The time scale had to be adapted to the conditions of the case study. The test rig fouling rate, that is the mass rate of contaminants entrained into the compressor, was 100 gr/h. In order to retain consistency between the four scenarios, it was assumed that the compressor in the current research work is operating in an environment similar to the environment where the experimental measurements of Tarabrin [8] were taken. It is reminded that Morini's et al. [28] relative roughness distributions used for the dry air scenarios were derived based on Tarabrin's [8] experimental data. In such an environment the dust concentration according to [31] is 0.06 gr/m3. The volume rate of the case study compressor is 16.7 [m3/s], therefore the contaminant ingestion rate equals to 2.8 10-5 [kg/s]. On the other hand, the equivalent contaminant ingestion rate for the experimental device, if it had a mass flow equal to the case study compressor would be 4.01 10-4 [kg/s]. Comparing the two contaminant ingestion rates, a scaling factor is defined in order to adjust the time scale used in the experiment to the time scale of the case study.

6. RESULTS AND DISCUSSION

The current study has two major goals:

i) to examine the effect of moisture and air filtering on gas turbine engine performance degradation due to fouling and,

ii) to present an integrated fouling model which in conjunction with a through-flow code and a gas turbine engine performance simulation tool, could substitute the methodology used so far in similar studies, where scaling factors of basic performance parameters are plugged in compressor stage-stacking methods.

The study focuses on the compressor, however the path that the operating point will follow, during the 1000 hours of operation, is externally defined, as it depends on the operating point of the whole engine. The compressor operating point in such simulation tools is uniquely defined through the boundary condition of either mass flow or exit static pressure and rotational speed. Neither of the two can be known beforehand, it has though in several cases as summarized by Tabarin [8], experimentally and computationally been proven, that in the case of compressor fouling, compressor pressure ratio and engine mass flow are in percentage equally decreased. Based on the above, the necessary boundary condition was indirectly defined as follows: An extra computational loop was added to the execution code where for each operating point the mass flow or the exit pressure, depending on whether the operating point was close to surge or stall, was progressively varied until the same in percentage reduction of pressure ratio and mass flow was detected.

Graphs on figures 1,2,3 and 4 show the decrease of pressure ratio and mass flow, as well as the decrease of the isentropic efficiency as the deposits built up with time.

Regarding the pressure ratio - mass flow variation, it is in all cases, as expected reducing with operating time. Reduction is slightly delayed though for the cases of filtered air. Especially in the less severe of the four scenarios, the 1st one, fouling starts to have appreciable effect on mass flow pressure ratio reduction, after the first 400 hours of operation.

Based on graph of figure 5 it turns out that the presence of a filter has an offsetting impact on pressure ratio reduction, that is when humidity is present, pressure ratio reduction is doubling. On the other hand, according to the trends demonstrated in figure 6, humidity has a far greater impact on compressor pressure ratio reduction when the air is unfiltered as opposed to the case where the air is filtered.

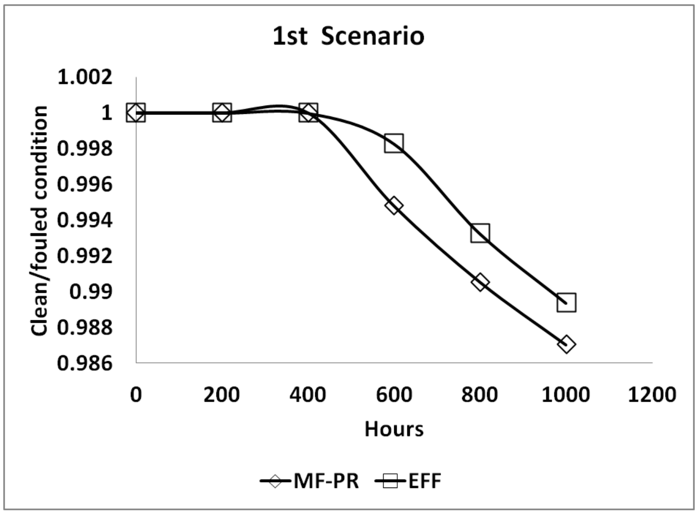

Figure 1: Compressor performance parameters variation, according to 1st scenario.

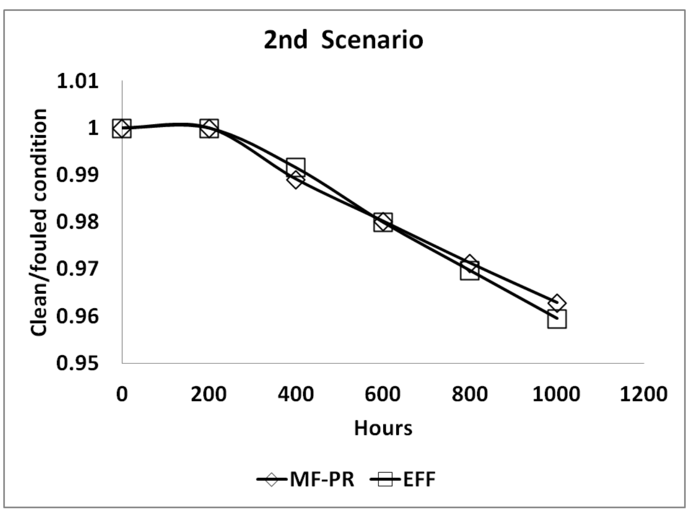

Figure 2: Compressor performance parameters variation, according to 2nd scenario.

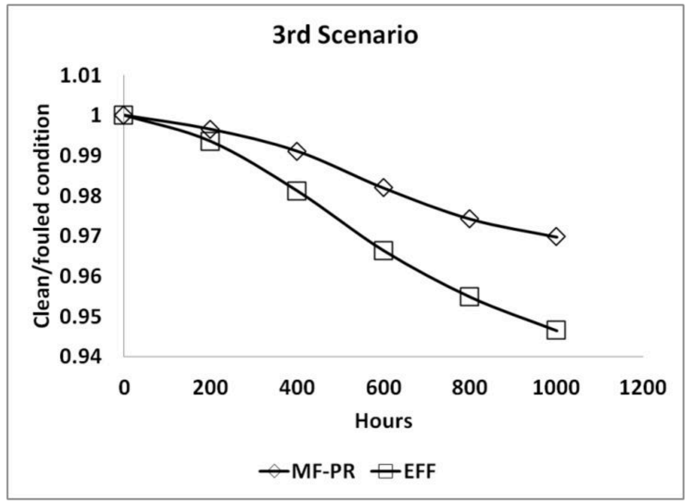

Figure 3: Compressor performance parameters variation, according to 3rd scenario.

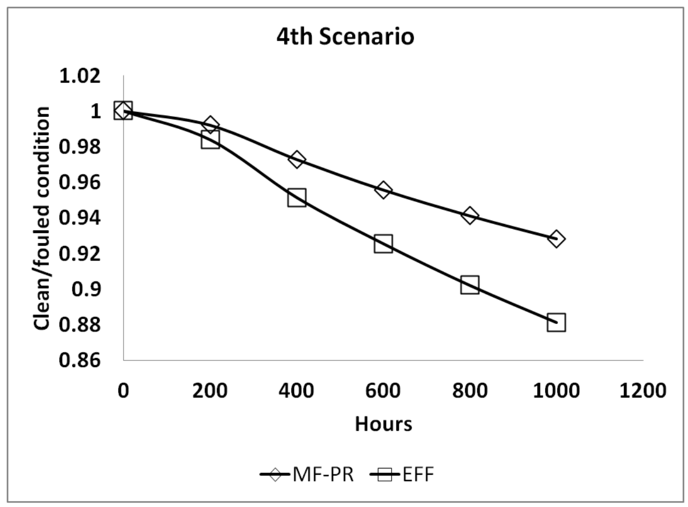

Figure 4: Compressor performance parameters variation, according to 4th scenario.

Regarding case specific pressure ratio versus isentropic efficiency reduction it can be seen that for unfiltered air scenarios, pressure ratio lags in reduction compared to isentropic efficiency (Figures 3,4). The exact opposite trend seems to rule in the two first scenarios where the air is filtered (figures 1,2). In particular, the relative trends spotted in the third scenario - stage 37 blades are fully fouled and the air is dry - are also verified by Melino et al [28] who examined fouling in similar operating conditions.

Finally in figure 7 the variation of total enthalpy rise through the compressor is plotted versus operating hours. Enthalpy rise is ruled by the pressure ratio and the isentropic efficiency. Efficiency drop leads to increased enthalpy rise where as pressure ratio decrease causes a drop in enthalpy rise. Based on the diagram, the enthalpy rise tends to increase with operating time when the air is unfiltered, whereas this trend reverses in the case of filtered air. Obviously this will not lead to increased output power because the decreased pressure ratio will cause a decrease in turbine power.

Accuracy of the results is always judged against computational time consumed. For SOCRATES, a converged solution for a certain operating point comes on average in one and a half minute for a core i7 standard laptop PC. This renders the current methodology applicable for optimization studies. In particular, as long as SOCRATES is integrated with a 0-D gas turbine performance simulation tool, then the hybrid calculation tool that will emerge, could introduce fouling in much greater detail, not only for optimization studies as mentioned above, but also for engine health monitoring assessment. For this type of studies, computation time consumption and correct qualitative response are the two most important characteristics. Quantitative weaknesses are to a certain extent canceled out, when similar cases are compared.

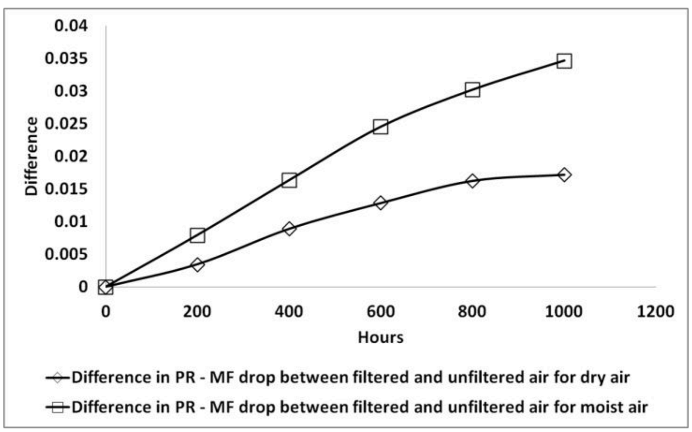

Fig. 5. Effect of Filter in PR - MF drop.

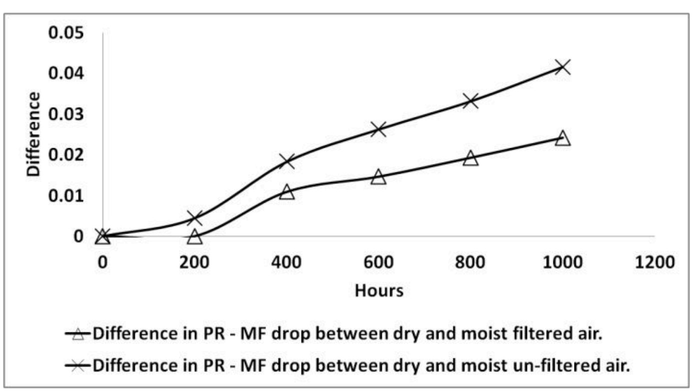

Fig. 6. Effect of Moisture in PR - MF drop.

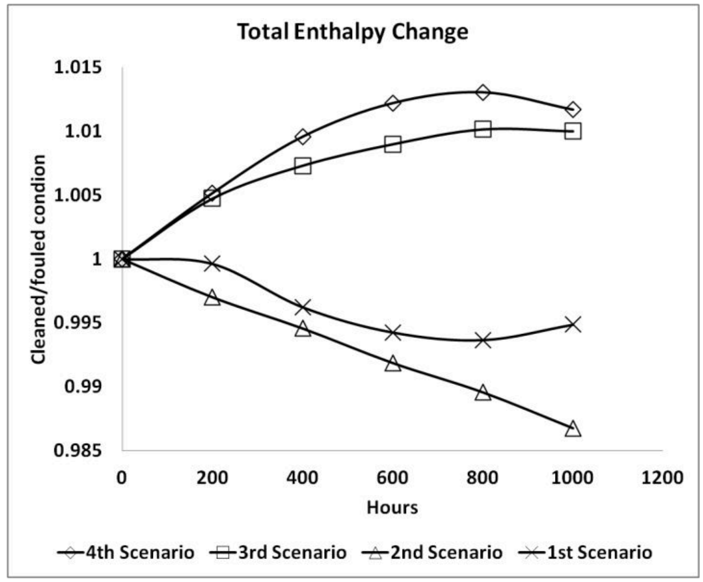

Fig. 7. N-curve of the 9T SRAM cell with different MN3/MN1 ratios

7. CONCLUSIONS

In the current study a streamline curvature based flow simulation tool, was used to assess the effect of the two ruling factors of compressor fouling: i) Concentration and size of contaminants present in the incoming flow and ii) moisture level of the air. For this study, four relevant operating scenarios were conceived and an integrated fouling loss model, developed by the authors was used. The model was extended to address the effect of degree of exposure of blades to fouling. Major findings are summarized below: Compressor performance decrease due to increased blade surface "stickiness" is stronger compared to the corresponding decrease caused by the absence of a filter. Moreover in the case of unfiltered air, regardless of the blade surface stickiness level, pressure ratio decrease is smaller compared to efficiency decrease. Finally the relevant efficiency - pressure ratio decrease, will define the sign of the enthalpy change trend.

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2021-01-11

Templalexis I, Pachidis V, Hasani H. (2021) Comparative assessment of fouling scenarios in an axial flow compressor. In: ASME Turbo Expo 2020: Turbomachinery Technical Conference and Exposition, London, 21-26 September 2020.

https://doi.org/10.1115/GT2020-14393