

Multi-Sensor Diagnostics of a Horizontal Vacuum Belt Filter Using Infrared Thermography and Differential Pressure Measurement: Industrial Application at Metalkol SA

Mr. Rolly Banza Kasongo¹, Mr. Jules Muteba Nyeke²,
Mr. David Mubanga Kulaila³, Prof. Jean-Claude Mukaz Ilunga⁴

¹Assistant, Maintenance, Institut Supérieur des Techniques Appliquées

²Professor, Maintenance, Institut Supérieur des Techniques Appliquées

Abstract

Monitoring the condition of vacuum belt filters is essential to minimize degradation in the filtration process. This study proposes a multi-sensor approach combining differential pressure measurement and infrared thermography to diagnose a horizontal vacuum belt filter operated at Metalkol SA. A series of spot measurements was conducted, and the data were processed using MATLAB based on differential pressure, average cake temperature, and a global health index. The results show an increase in differential pressure from 0.55 to 0.91 bar during the campaign, accompanied by a change in average temperature. A correlation coefficient of 0.89 was obtained between these two parameters. Combining pressure and thermographic indicators thus improves the interpretation of the filter's condition and helps guide condition-based maintenance operations.

Keywords: vacuum belt filter; differential pressure; infrared thermography; diagnostics; condition-based maintenance; clogging

1. Introduction

Horizontal vacuum belt filters are used in solid-liquid separation processes, particularly in the mining industry [13], [19]. Their operation depends on the condition of the filter belt, the filter cake, and the vacuum system [15]. The onset of clogging or an anomaly can lead to increased filtration resistance [28], performance degradation, and, ultimately, unplanned maintenance interventions.

Pressure differential serves as a useful indicator for monitoring the overall evolution of filtration conditions. However, its aggregate nature limits the ability to pinpoint the location of anomalies. Infrared thermography provides complementary spatial information by enabling the identification of thermal variations across the filter surface [17], [18], [32]. Combining these two techniques can thus improve the interpretation of the equipment's condition. Despite these advances, applications specific to horizontal vacuum belt filters remain relatively limited, and research into the multi-parameter diagnosis

of these filters—particularly regarding the combined use of pressure and thermographic data [18], [20]—remains scarce. This situation represents the primary scientific gap addressed in this work. The objective of this study is therefore to develop and evaluate a multi-sensor approach combining differential pressure measurement and infrared thermography for the diagnosis of a horizontal vacuum belt filter operated at Metalkol SA. Experimental data are analyzed using MATLAB to investigate the relationship between pressure and temperature indicators and to construct a comprehensive health index designed to support condition-based maintenance.

2. Materials and methods

2.1. System studied

The system under study is a horizontal vacuum belt filter used in Metalkol SA's industrial process. Its operating principle relies on the movement of a filter belt over a vacuum suction system. Liquid gradually passes through the filter cake and the belt, while solid particles are retained. Changes in the filter cake can alter the resistance to fluid flow; monitoring the pressure difference therefore provides a way to indirectly observe this evolution..

2.2. Monitored parameters

Two main parameters were selected:

- the pressure difference ΔP ;
- the filter cake temperature.

These two parameters are used in conjunction to improve the interpretation of the filter's condition. The pressure difference provides global information, whereas thermography yields spatial information. This complementarity forms the core principle of the methodology proposed in this study.

2.3. Measurement of the pressure difference

The pressure difference between two measurement points is defined by:

$$\Delta P = P_{\text{amont}} - P_{\text{aval}}$$

When the values are analyzed in terms of depression, their absolute value can be used:

$$|\Delta P| = \text{absolute value of } \Delta P$$

The relative pressure loss is also introduced in the form:

$$\Delta P_{\text{real}} = \frac{\Delta P_{\text{abs}} - \Delta P_{\text{nom}}}{\Delta P_{\text{nom}}} \times 100$$

Or :

- ΔP_{abs} represents the measured pressure difference ;
- ΔP_{nom} represents the reference pressure difference corresponding to a situation considered normal.

This expression allows the evolution of the pressure drop to be related to a reference condition.

As a first approximation, the pressure drop across a porous medium can be described by Darcy's relationship:

$$\Delta P = \mu \times L \times \frac{u}{k}$$

Avec :

- ΔP : pressure loss;
- μ : fluid viscosity;
- L : thickness of the filter medium or the cake;
- u : superficial filtration velocity;

- k : permeability of the medium

2.4. Thermographic measurement

Thermal observations are performed using a FLIR E96 infrared camera (Figure 1.b).

Infrared thermography provides a spatial representation of the thermal radiation emanating from the observed surface. The radiative flux is given by :

$$\Phi = \varepsilon \sigma T^4 + (1 - \varepsilon) \Phi_{\text{ambient}}$$

Or :

- Φ is the measured radiative flux;
- ε represents the emissivity of the surface;
- σ is the Stefan-Boltzmann constant;
- T is the absolute temperature;
- Φ_{ambient} represents the reflected radiation coming from the environment.

The practical value of thermography in this study lies primarily in enabling the localization of specific thermal zones on the filter cake.



Figure 1 : Instruments used for data acquisition: (a) SA GAUGE vacuum gauge; (b) FLIR E96 infrared camera.

2.5. Average cake temperature

The temperatures measured at the two positions are used to calculate an average temperature:

$$T_{\text{med}} = \frac{T_{\text{amont}} + T_{\text{aval}}}{2}$$

The temperature difference between the two positions is given by:

$$\Delta T = T_{\text{aval}} - T_{\text{amont}}$$

These quantities make it possible to characterize the thermal evolution of the system during the measurement campaign.

2.6. Normalization of parameters

To compare different quantities on the same scale, normalization is used.

For a variable X , the general form adopted is:

$$X_{\text{norm}} = \frac{X - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}}$$

This expression allows the values to be scaled to a range between 0 and 1 as X varies between X_{min} and X_{max} .

The same logic is applied to the pressure and temperature indicators included in the calculation of the health index.

2.7. Overall health index of the band

An overall band health index, denoted ISB, combines information from pressure and temperature.

The weightings used are:

$$a = 0,6$$

$$b = 0,4$$

The index is then expressed by:

$$ISB = 100 \times [0.6 \times (1 - \Delta P_{norm}) + 0.4 \times (1 - T_{norm})]$$

Or :

- ΔP_{norm} is the normalized pressure difference;
- T_{norm} is the normalized thermal parameter..

In this formulation, an increase in degradation parameters leads to a decrease in the ISB.

The index can therefore be interpreted as a health indicator: a high value reflects a state closer to the reference condition, whereas a drop in the index indicates degradation.

However, the coefficients 0.6 and 0.4 reflect the choice made in the thesis and should be regarded as weightings proposed within the scope of this study.

3. Experimental procedure

The methodology is based on a one-off measurement campaign over a 6-month period

The processing chain is organized according to the following steps (Figure 2):

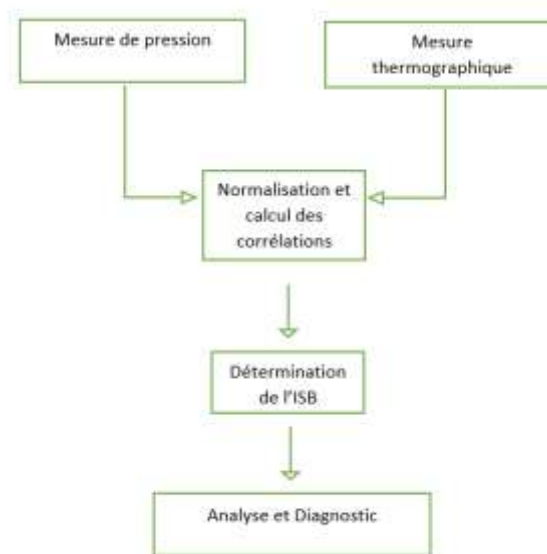


Figure 2 : Methodological framework

The data are collected during specific campaigns and then processed in MATLAB to establish correlations and calculate indicators.

4. Experimental results

4.1. Measurements obtained

The main measures presented are summarized in the table 1.

Table 1: Key points of the adopted measures

Mesure	Tamont (°C)	Taval (°C)	ΔP (bar)	Thickness (mm)
1	21,6	21,2	0,55	50
2	23,1	23,0	0,53	50
3	21,8	23,5	0,64	50
4	24,5	24,7	0,67	50
5	25,7	24,7	0,69	50
6	26,6	26,5	0,71	50
7	27,7	27,5	0,75	50
8	29,7	28,3	0,80	40
9	26,7	27,0	0,84	40
10	29,7	29,9	0,91	40

The data show an overall increasing trend in the pressure difference.

The pressure difference shows an overall increasing trend during the campaign, rising from 0.55 bar to 0.91 bar. This trend reflects an increase in the overall resistance to fluid flow under the studied conditions.

4.2. Average Temperature Trend

From the upstream and downstream temperatures, the average temperature is calculated by the formula.

$$T_{\text{moy}} = \frac{T_{\text{amont}} + T_{\text{aval}}}{2}$$

This value generally increases over the course of the study period.

However, the thermal trend must be interpreted by taking into account the acquisition conditions and the environment. Thermography therefore serves primarily as a means of comparison between zones and between operating conditions.

4.3. Correlation between pressure and temperature

The relationship between the pressure difference and the average temperature was analyzed using MATLAB (Figure 3).

The correlation coefficient obtained is:

$$r = 0,89$$

Linear correlation can be expressed in general terms as:

$$r = \frac{\sum(P_i - \bar{P})(T_i - \bar{T})}{\sqrt{\sum(P_i - \bar{P})^2 \times \sum(T_i - \bar{T})^2}}$$

Or :

- P_i is the pressure value associated with measurement i ;
- T_i is the corresponding average temperature;
- $\bar{P}$ is the average of the pressure values;
- $\bar{T}$ is the average of the temperatures..

For the campaign under study, $r = 0.89$ indicates a strong positive relationship between the two variables.

This correlation highlights an association between the change in pressure difference and the change in average temperature under the conditions studied.

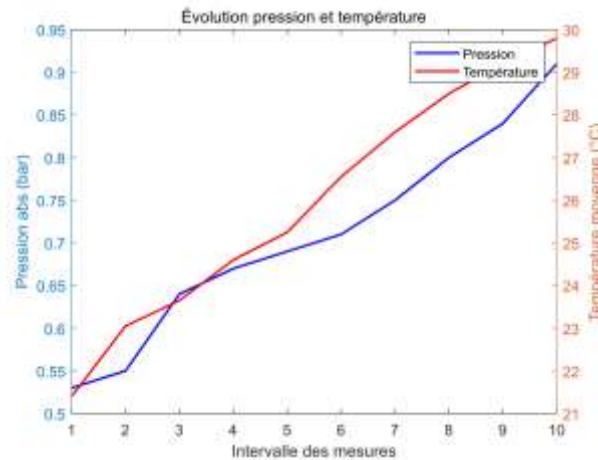


Figure 3: Joint evolution of ΔP and the average temperature

This correlation means that high pressure values are generally associated with higher average temperatures in the data under consideration.

4.4. Comparison before and after cleaning

Comparison of the two series shows a generally lower level of pressure difference after cleaning. This observation (Figure 4) is consistent with a reduction in filtration resistance, assuming comparable operating conditions.

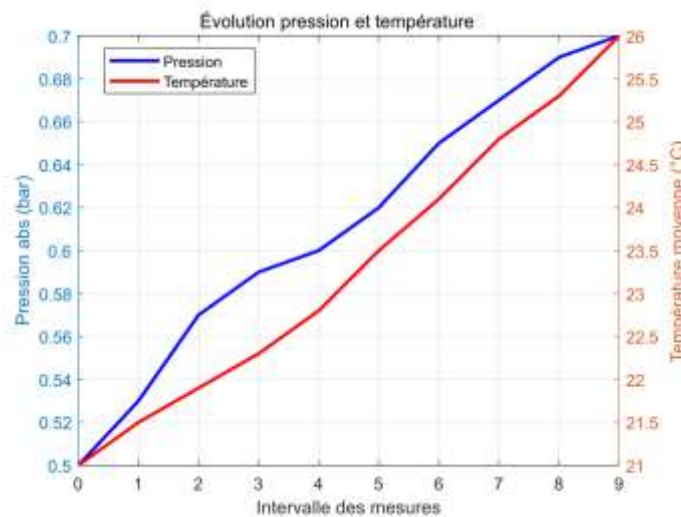


Figure 3 : Evolution of pressures and temperature after cleaning

5. Troubleshooting

The multi-sensor approach makes it possible to correlate pressure trends with thermographic observations.

Table 2: Diagnosis of anomalies, following the four types of defects.

Observed state	ΔP	Thermal signature	Interpretation
Normal operation	Stable	Homogeneous	Acceptable condition

Observed state	ΔP	Thermal signature	Interpretation
General clogging	Gradual increase	Relatively homogeneous variation	Increased resistance
Localized clogging	Local variation	Localized thermal zone	Localized defect
Tear	Local disturbance	Specific thermal zone	To be confirmed by inspection
Air leak	Vacuum instability	Localized anomaly	Vacuum circuit check

5.1. Overall sealing

Global clogging can be associated with a progressive increase in ΔP accompanied by a relatively homogeneous thermal evolution.

In this case, the increase in resistance to fluid flow is observed globally across the system (Figure 5).

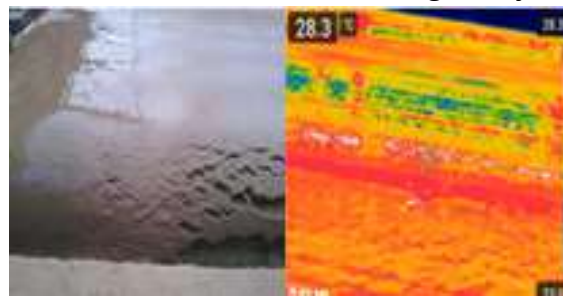


Figure 4 : Example of a thermal signature observed in the filtration zone.

5.2. Local sealing

Localized clogging can manifest as a thermal anomaly confined to a specific area of the cake.

The pressure may then indicate general deterioration, while thermography provides an indication of the problematic area's location.

5.3. Tear in the tape

A localized disruption of airflow, potentially accompanied by a localized pressure variation and a distinct thermal zone.

Such an observation must nevertheless be confirmed by direct inspection before being considered a definitive identification of the failure.

5.4. Air leak

An air leak can cause a variation in the vacuum level and a localized thermal signature.

The combination of these two observations thus serves as an indicator warranting a targeted inspection.

6. Analysis and discussion

The main contribution of this approach lies in the complementarity of the two techniques.

Pressure measurement makes it possible to monitor the overall change in the filter's condition:

$\Delta P \uparrow \rightarrow$ flow resistance $\uparrow$

Thermography, for its part, provides spatial information :

Thermal signature $\rightarrow$ potential location of the anomaly

Combining these two pieces of information therefore yields a richer diagnosis than an analysis based solely on pressure difference.

Thermography essentially enables localization, whereas pressure difference allows for quantification.

7. Use of the HIC for status monitoring

The proposed index makes it possible to combine the two indicators.

The formula can be recalled here,

$$ISB = 100 \times [0.6 \times (1 - \Delta P_{norm}) + 0.4 \times (1 - T_{norm})]$$

A relatively favorable state is associated with a high index.

As the normalized pressure difference and temperature increase, the health term decreases.

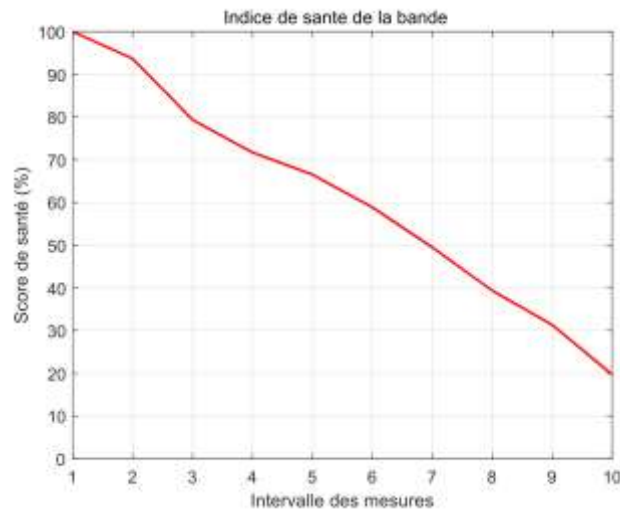


Figure 5 : Evolution of the overall health index of the cloth

The indicator can therefore be used to compare multiple measurement campaigns and observe the general trend of the filter's condition (Figure 6).

Its primary value lies in the synthesis of information; it avoids the need to consider various indicators separately during an initial assessment.

8. Proposed maintenance approach

Based on the results obtained, a simple procedure can be proposed

During a periodic inspection, the operator can measure the pressure difference, capture a thermographic image, calculate the average temperature, compare the values with those from previous campaigns, and determine the HIC..

An evolution of the type:

$\Delta P \uparrow + \text{temperature} \uparrow +$ A localized thermal anomaly can then lead to a more in-depth inspection of the strip or the cake..

This approach does not replace physical inspection but allows maintenance operations to be better targeted.

9. Study limitations

The main limitation relates to the point-in-time nature of the data; the data represent only a snapshot of the filter's condition, and their interpretation depends on the acquisition conditions. Furthermore, data processing is performed after the measurements are taken, introducing a time lag between acquisition and diagnosis.

The measurements are also influenced by instrument characteristics and acquisition conditions. The pressure gauge used has a range of 0 to -100 kPa, while the FLIR E96 camera features a resolution of 320×240 pixels and a thermal sensitivity of less than 50 mK. However, a quantitative characterization of the overall uncertainty would require access to the instruments' complete metrological specifications as well as the exact measurement conditions.

Consequently, the study does not yet make it possible to establish a temporal predictive model for failure.

Furthermore, the limited number of observations does not allow for the definitive setting of universal industrial thresholds for the HIC.

Finally, economic gains and reduced downtime are expected benefits of the approach, but they are not quantified in sufficient detail in the dataset used here.

10. Conclusion

This study presented a multi-sensor diagnostic method applied to a horizontal vacuum belt filter at Metakol SA.

The method combines differential pressure measurement with infrared thermography. The former provides global information on the evolution of filtration conditions, while the latter allows for the observation of the spatial temperature distribution.

Experimental data show an overall increase in the pressure difference, from 0.55 bar to 0.91 bar, over the course of the study period. The average temperature also changes, and a correlation coefficient of 0.89 is obtained between the pressure and the average temperature.

The study also introduces an overall health index :

$$HIC = 100 \times [0.6 \times (1 - \Delta P_{norm}) + 0.4 \times (1 - T_{norm})]$$

This indicator synthesizes the information provided by the two parameters and can serve as a simple diagnostic aid.

The proposed methodology is therefore valuable for periodic inspections and for the condition-based maintenance of the filter. It provides a basis for guiding maintenance operations according to the observed condition of the equipment.

Moving towards predictive maintenance would require increasing the number of measurement campaigns, ensuring more extensive temporal monitoring, and eventually automating data acquisition and analysis.

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