# Surface temperature of the exposed silo face as quick indicator of the decomposition process of maize silage

# Povrchová teplota odkrytého čelního profilu siláže jako rychlý indikátor procesu rozkladu kukuřičné siláže

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## Abstract

Silage temperature and oxygen concentration are critical parameters for controlling the silage process. Anaerobic condition with lower and stable temperature is necessary for quality silage making. However, when the silo is opened or if there are any failures (e.g. at the cover or at the walls) the anaerobic environment is changed to an aerobic state. That caused intensive decomposition process allied to increase of the temperature in the problematic silage layers. The objective of the current study is to evaluation of infrared thermography technique possibilities for measurement of surface temperature of the maize silage under conditions representative of an exposed face silo, interpretation of measured values and detection of layers and areas with intensive decomposition process.

**Keywords:** decomposition process, infrared thermography, silage, surface temperature

## Abstract in native language

Teplota siláže a koncentrace kyslíku jsou kritické parametry, důležité při řízení procesu silážování. Anaerobní podmínky s nižší a stabilní teplotou siláže jsou nezbytné pro zachování její kvality. Pokud dojde k otevření sila vlivem odběru siláže nebo vlivem existujících poruch vzduchotěsného krytu či stěn sila, anaerobní podmínky se změní na aerobní. Tento stav způsobí v problematických vrstvách siláže iniciaci intenzivního mikrobiálního rozkladného procesu spojeného s rostoucí teplotou. Cílem této práce je experimentální ověření možnosti využití infračervené termografie pro měření povrchových teplot odkrytého čela siláže a následná interpretace zjištěných teplotních stavů s ohledem na rozkladný proces.

**Keywords:** infračervená termografie, povrchová teplota, proces rozkladu, siláž

## Introduction

Maize silage is significant component of the dairy feed base and material for anaerobic fermentation process at the biogas plants. The maize silage is fermented phytomass whose structure and consistence is appropriate for feeding ruminant animals (e.g. dairy cows) or for energy biogas transformation. As a consequence, maize silage is an increasingly important production factor in agriculture mainly in sector of dairy production and renewable energy resources. Quality of the silage is an essential prerequisite for maintaining production efficiency and for reducing costs of production.

However, in order to preserve the nutritional quality of the silage certain essential conditions need to be met during the storage process. Respiration is the primary cause of silage quality loss and this depends on the supply of oxygen ($O_2$), heat and water (McDonald, et. al. 2002). In practice silage in dairy farms is usually transported from the field to the storage facility and spread out in thin layers. Each layer is then compacted, for instance with a heavy tractor, before the next layer is added. Immediate action must be taken to prevent oxygen entering the silage stack, and therefore the silage stack is then sealed using airtight covers. Silage temperature is initially increased due to fermentation. After the initial fermentation period is over, silage temperature should be lower and stable, and any significant increases in silage temperature are associated with aerobic decomposition. The conservation process prevents the digestible matter in the silage from decomposing (McDonald, et al. 1991). Failures of the covering system (e.g. tears in the plastic covering, cracks in the walls) cause rapid decomposition of adjacent silage. In order to ensure adequate preservation of the silage during the entire storage period, it is important to be able to detect potential changes in specific physiochemical properties of the silage that can act as indicators of silage decomposition. During the decomposition process, the dry matter breaks down into $H_2O$ and $CO_2$ with a release of heat which is not possible to detect under the sealed covers (McDonald, el. al 1991). Losses of silage dry matter up to 75% were only visible to a very small extent (McDonald, et al. 2002). However, by constantly monitoring the oxygen level, pH or temperature inside the silage during storage, the status as well as the quality of the silage can be evaluated (Pippard, et al. 1996). Aerobic deterioration resulted from activity of yeasts and molds utilizing residual water-soluble carbohydrates and lactic acid, resulting in with a pH value rising, dry matter loss and energy release (Muck, et al. 1991). In addition, the growth of molds may produce mycotoxins, which threaten the health of humans and animals (Pahlow, et al. 2003).

Silage temperature variations after fermentation are a function of air and soil temperatures. Infrared thermography technique can be used for monitoring silage surface temperature at different locations. Any significant increases in temperature occurring during silage decomposition can be quickly detected. It is useful to detect the decomposition process in its early stages, so as to achieve a more effective conservation process (Green, et al. 2009). Balaras and Argiriou (2002) state that thermography can be used for diagnosis of building energy losses, but also to non-destructive test of ventilation, heating, air conditioning and electric systems. Other authors used thermography for sensitivity analysis of the process to the emissivity, reflection, environmental conditions and surface colour (Barreira and de Freitas, 2007). However many papers deal with use of IR thermography for non-traditional applications. These include use thermography in drying technique (Vitázek and Tirol 2008) or for calculation of heat losses of boilers for combustion biomass (Vítěz and Trávníček 2011) or for non-contact thermometry in the milk acquisition process (Karas and Gálik 2004).

Our objectives are to evaluation of infrared thermography technique possibilities for measurement of surface temperature of the maize silage under conditions representative of an exposed face silo, interpretation of measured values and detection of layers and areas with intensive decomposition process.

## Materials and Methods

The experiment was carried at four different locations. Chosen silage bunker silos have similar technological solution. Exposed silos face has been measured five minutes after mechanical unloading process. First survey was performed at farm Klopina during the winter season (6$^{th}$ march 2013). Conditions of thermography measurement: cloudy conditions, air temperature about 8 °C, air velocity 0.40 $m \cdot s^{-1}$, relative humidity 55%. The analyzed object is located in Klopina (lat 49°48´55´´N, long 17°1´3´´E) Šumperk region, Czech Republic. This monolithic steel concrete bunker silo is overall 42.50 m wide, 47.50 m long and 3.50 m high (exterior sizes). Sealing of bunker silo is from polyethylene plastic sheeting (thickness 0.2 mm). The plastic cover is anchored to the silage with used tyres that keep it from flapping. This cover protects the surface of the silage against air penetration. Second survey was performed at farm Švábenice during the winter season (15$^{th}$ march 2013). Conditions of thermography measurement: cloudy conditions, air temperature -3.5 °C, air velocity 0.33 $m \cdot s^{-1}$, relative humidity 45%. The analyzed object is located in Švábenice (lat 49°16´46´´N, long 17°6´58´´E) Vyškov region, Czech Republic. This monolithic steel concrete bunker silo is overall 35.50 m wide, 65.50 m long and 3.00 m high. Cover of the silage bunker is the same with first case.
The next analyzed object is located in Třeština (lat 49°47'39.602"N, 16°58'10.855"E) Šumperk region, Czech Republic. The measurement was performed on 6$^{th}$ march 2013. Conditions of thermography measurement: cloudy conditions, air temperature about 9 °C, air velocity 0.40 $m \cdot s^{-1}$, relative humidity 59%. This monolithic steel concrete bunker silo is overall 37.00 m wide, 85.00 m long and 4.50 m high. Covering of the bunker silo is plastic.
The last object is located in Lukavice (lat 49°49'15.539"N, 16°54'41.882"E), Šumperk region, Czech Republic. Here the measurements were performed during winter season too (5$^{th}$ February 2014). Conditions of thermography measurement: cloudy conditions, air temperature about 2 °C, average air velocity 1.2 $m \cdot s^{-1}$ and relative humidity 67%. There are three bunker silos from monolithic steel concrete that are overall 66.50 m wide, 71.00 m long and 4.50 m high.
Infrared thermography survey of maize silage silo face was performed by FLUKE thermal camera. For thermal imaging measurement purposes was measured the air temperature, air humidity, distance from the monitored object and material emissivity. Determination of material emissivity was executed by creation of measuring points on the materials, where was executed thermal analyses. At these points was measured temperature with using OMEGA HH11 contact thermometer (accuracy of temperature measurement: ± 0.1 °C). The most significant prerequisite was to prevent fluctuation of temperature in the course of time. The aforementioned point

was also monitored using FLUKE Ti32 thermal camera. In case that the temperature values proved to differ, the temperature in the thermal camera was calibrated by the means of setting up the emissivity value in the user interface of this device. The final emissivity value was determined at the time when the temperature values on both the devices were balanced. Infrared thermography for the evaluation of heat dispersions in buildings perform at their best if a minimum temperature difference of 10-15 °C between the external and internal environment is guaranteed.
The air temperature and relative humidity were measured using KIMO AMI 300 multifunction equipment. The air velocity and temperature were measured with using a telescopic vane probe type HET 14 (in the range of 0.8 to 25.0 m/s and -20 to 80 °C) featuring the temperature measurement accuracy of ±1 °C. The relative humidity were measured with using a telescopic hygrometry probe SVTH (in the range of 5.0 to 95.0% relative humidity) featuring the measurement accuracy of ±4%. The temperature and humidity were measured in the close vicinity of the thermal camera and measuring equipment, and the arithmetic mean was subsequently calculated on the basis of these values. The reflected temperature was not measured because any heat sources were not in the surroundings, which could influence the measurement. The distance of the camera from measuring object was determined using Leica DISTOtm A5 laser EDM device (measurement accuracy: ± 1.5 mm at a distance between 0.2 and 200 m). The thermal imaging measurement as such was conducted using Fluke Ti32 thermal camera (FOV: 45°). The average temperature of the surface was calculated using Fluke SmartView 3.2 software in which each pixel of the video recording was allocated to one temperature value. An arithmetic mean was subsequently created on the basis of all values. Boundary conditions of infrared thermography measurement are presented in Table 1.,Table 2.,Table 3. and Table 4.

Table 1. The boundary conditions of the infrared thermography survey in Klopina

| No. | Object | Material | $\varepsilon$ [-] | $t_a$ [°C] | $\varphi$ [%] | l [m] | $t_{max}$ [°C] |
|---|---|---|---|---|---|---|---|
| 1 | Silage silo face 1 (Klopina) | Maize silage | 0.95 | 8.5 | 54 | 6 | 16.6 |
| 2 | Silage silo face 2 (Klopina) | Maize silage | 0.95 | 8.7 | 55 | 11 | 15.6 |
| 3 | Silage silo face 3 (Klopina) | Maize silage | 0.95 | 8.5 | 54 | 5 | 15.2 |
| 4 | Silage silo face 4 (Klopina) | Maize silage | 0.95 | 8.6 | 54 | 10 | 11.9 |

Table 2. The boundary conditions of the infrared thermography survey in Švábenice

| No. | Object | Material | $\varepsilon$ [-] | $t_a$ [°C] | $\varphi$ [%] | l [m] | $t_{max}$ [°C] |
|---|---|---|---|---|---|---|---|
| 1 | Silage silo face 1 (Švábenice) | Maize silage | 0.95 | -3.4 | 45 | 4 | 3.9 |
| 2 | Silage silo face 2 (Švábenice) | Maize silage | 0.95 | -3.7 | 44 | 4 | 10.1 |
| 3 | Silage silo face 3 (Švábenice) | Maize silage | 0.95 | -3.3 | 44 | 3.5 | 9.9 |
| 4 | Silage silo face 4 (Švábenice) | Maize silage | 0.95 | -3.5 | 45 | 3.5 | 8.1 |

Table 3. The boundary conditions of the infrared thermography survey in Třeština

| No. | Object | Material | ε [-] | $t_a$ [°C] | φ [%] | l [m] | $t_{max}$ [°C] |
|---|---|---|---|---|---|---|---|
| 1 | Silage silo face 1 (Třeština) | Maize silage | 0.95 | 9.1 | 59 | 6 | 23.1 |
| 2 | Silage silo face 2 (Třeština) | Maize silage | 0.95 | 9.2 | 59 | 7 | 19.3 |

Table 4. The boundary conditions of the infrared thermography survey in Lukavice

| No. | Object | Material | ε [-] | $t_a$ [°C] | φ [%] | l [m] | $t_{max}$ [°C] |
|---|---|---|---|---|---|---|---|
| 1 | Silage silo face 1 (Lukavice) | Maize silage | 0.95 | -2.0 | 67 | 4 | 9.0 |
| 2 | Silage silo face 2 (Lukavice) | Maize silage | 0.92 | -1.9 | 66 | 3.5 | 13.1 |

$\varepsilon$ Emissivity of material
$\varphi$ Relative humidity
$t_a$ Air temperature
$l$ Distance from measuring point
$t_{max}$ Maximal temperature in the area

For confrontation of thermography measurement results with characteristics of silage were performed completive analyses. For basic chemical and microbiological analyses, eight composite samples of each silage heap were taken from the areas of the silage profile with low and higher temperature. Analyses monitored basic characteristics such as pH, dry matter, lactic acid, acetic acid, ammonia nitrogen, aerobic bacteria, yeasts, molds and aerobic stability.

## Results

First investigation was effected at Klopina location. That is presented at Figure 1., Figure 2. Figure 3., and Figure 4. Right part of the silage bunker silo is presented in first thermogram (Figure 1.). We can see higher temperature mainly at border part. Layer with higher temperature is at all vertically profile and indicate more intensive aerobic decomposition process. That is caused by low intensity of silage compacting and higher level of air content in silage. Compacting of the border parts of bunker silo is more problematic for mechanization operation. On the floor of the bunker silo we can see next layer with higher temperature. That is caused by high level of moisture from silage juice. Supposedly, there are more organic nutrients in that layer and aerobic decomposition process is more intensive.

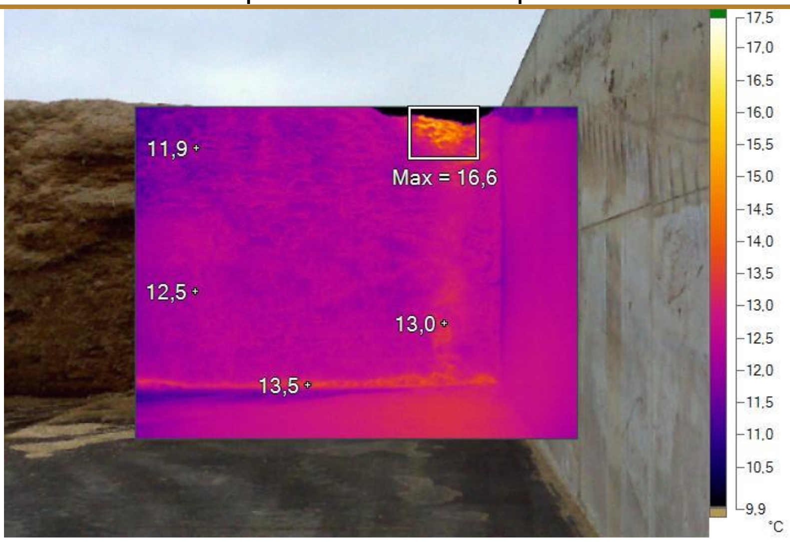


Figure 1. Thermogram of maize silage profile at Klopina location (part 1)

Middle part of the bunker silo is presented in second and third thermogram (Figure 2. and Figure 3.). We can see small areas with higher temperatures mainly at top part of the profile. That is caused by high aeration and loosening of surface layers of silage profile. Floor area with higher temperature is affected by different emissivity of the frozen silage juice. Difference between temperature of compacted silage profile and loosened silage is shown at Figure 3. We can see face of silage profile with comparable temperature values and loosened stack with higher level of temperature indicated more intensive aerobic decomposition process.

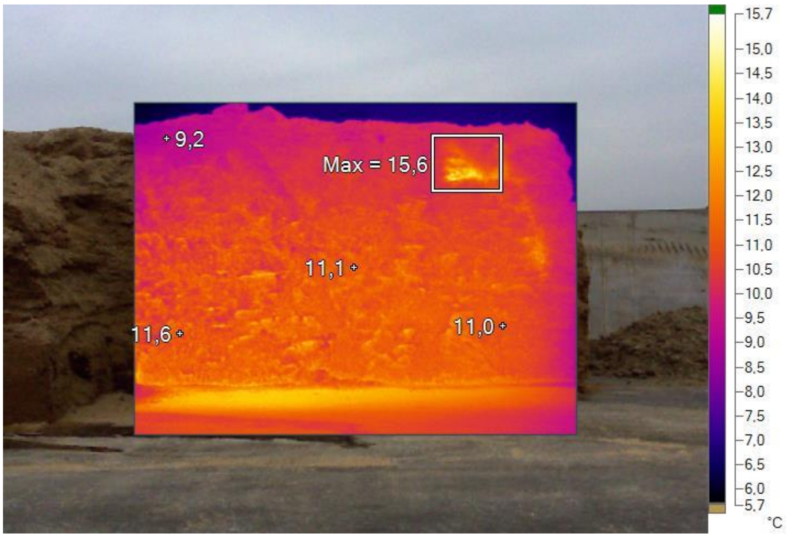


Figure 2. Thermogram of maize silage profile at Klopina location (part 2)


ISSN 1332-9049

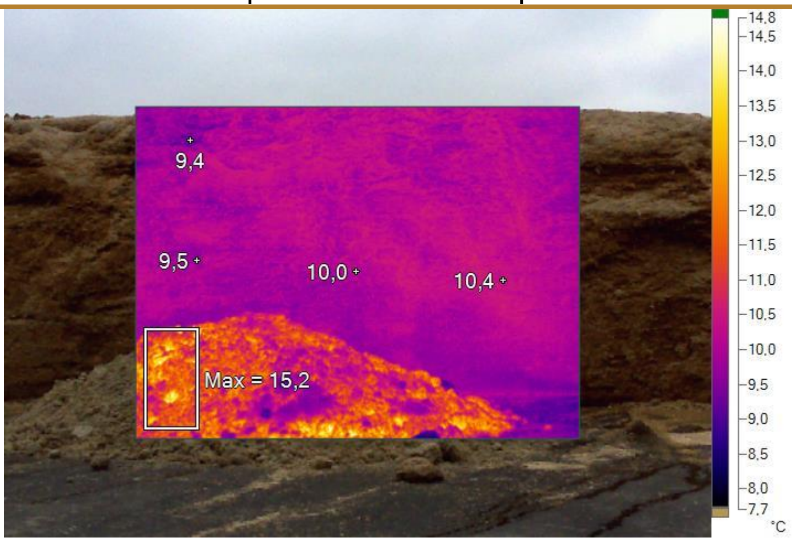


Figure 3. Thermogram of maize silage profile at Klopina location (part 3)

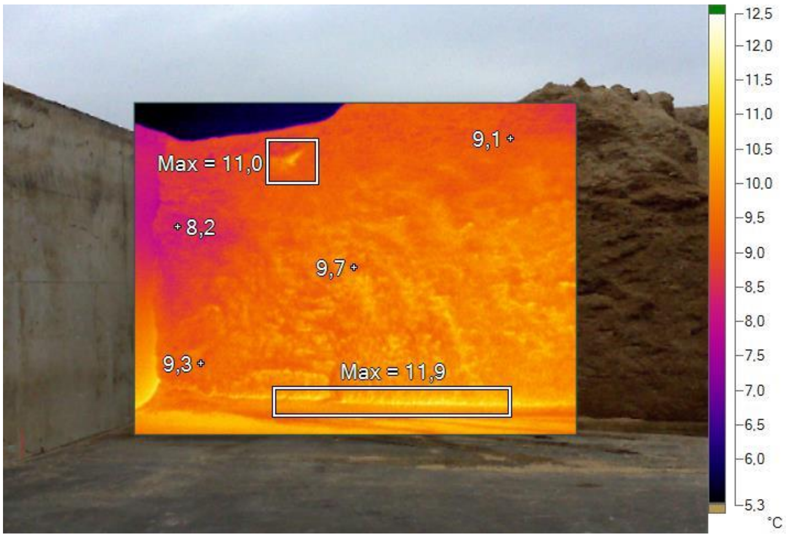


Figure 4. Thermogram of maize silage profile at Klopina location (part 4)

Thermogram of the left border of the bunker silo is presented at Figure 4. There is a situation similar to Figure 1. but values of silage temperature are not so high. Floor layer with high intensity of silage decomposition process is also similar.

Second investigation was effected at Švábenice location. That is presented at Figure 5., Figure 6., Figure 7. and Figure 8. Figure 5. present right border of the bunker silo. We can see significant temperature difference between some areas. That is caused partly by technology of silage compacting. There is higher level of aeration which supports aerobic decomposition process similar to Klopina case. Difference from situation at Figure 1. is in size of areas with higher temperature.

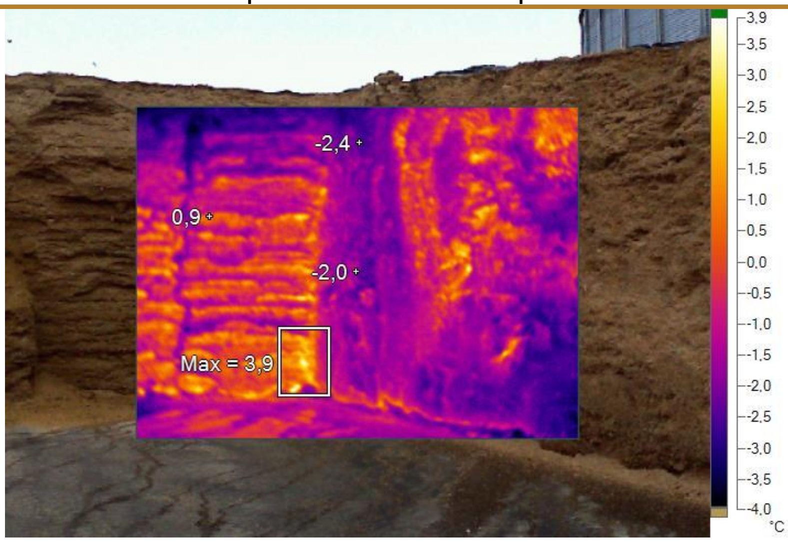


Figure 5. Thermogram of maize silage profile at Švábenice location (part 1)

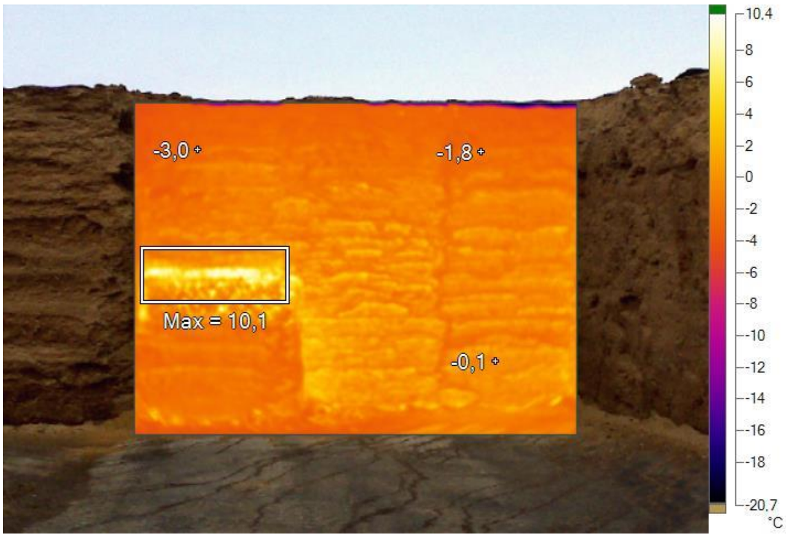


Figure 6. Thermogram of maize silage profile at Švábenice location (part 2)

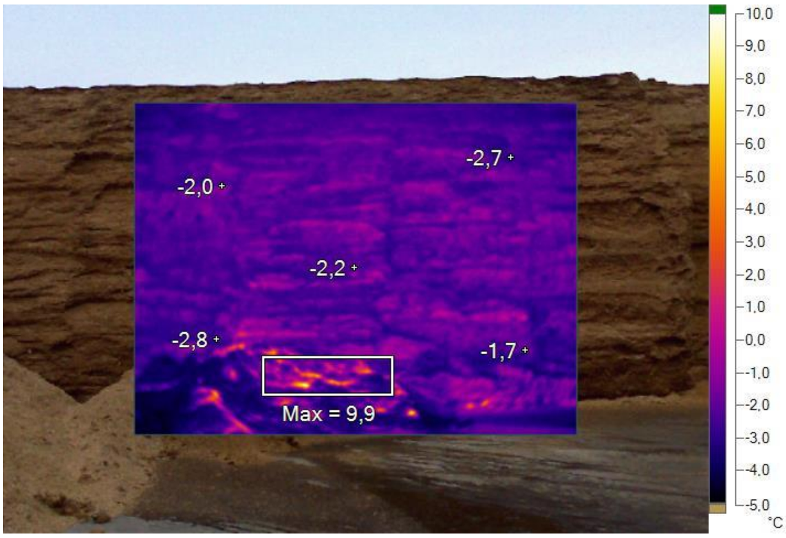


Figure 7. Thermogram of maize silage profile at Švábenice location (part 3)

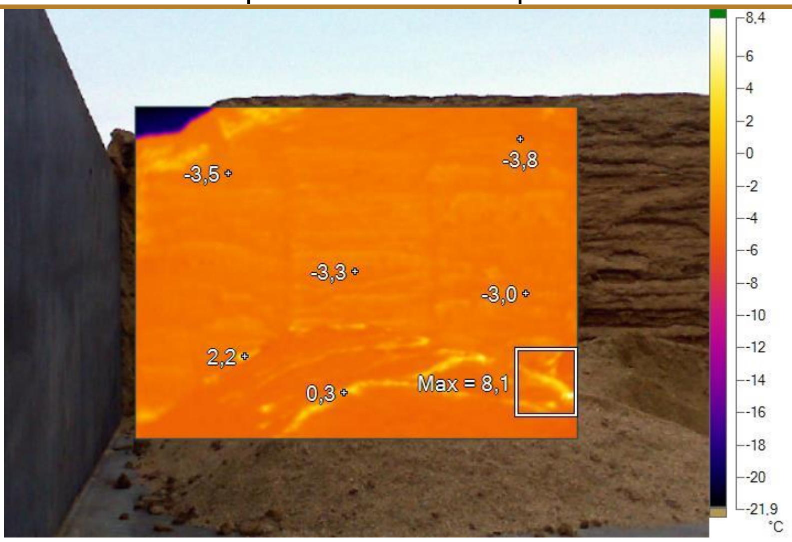


Figure 8. Thermogram of maize silage profile at Švábenice location (part 4)

Middle part of the face silage profile is presented at Figure 6. and Figure 7. As we can this thermogram present compacted silage profile and loosened silage stack. Compacted silage profile has more local areas with higher temperature. Figure 8. present thermogram of situation at right border of the bunker silo. We can see higher temperatures mainly at top part of the profile similar of Figure 1. If we compare these thermograms with situation in case Klopina that is evident more occurrence of layers with intensive decomposition process. Supposedly that indicates problems with technology of ensiling.

Third investigation was effected at Třeština location. That is presented at Figure 9. and Figure 10. Figure 9. presented right border of the silage profile. We can see significant difference of surface temperature mainly on the middle part of thermogram (max. temperature 23.1 °C). Figure 10. presented left border and middle part of the silage profile. There are some local areas with surface temperature differences. First area with significant higher temperature is situated near the covering of the silo (max. temperature (maximal temperature 18.1 °C) similar to Figure 5. and Figure 6. Next area is silage layer near the concrete flooring (maximal temperature 19.3 °C) similar to Figure 4. and Figure 10. Last investigation was effected at Lukavice location. That is presented at Figure 11. and Figure 12. Thermogram of first bunker silo is presented at Figure 11. Significant temperature differences are situated on the middle part of silage profile again. As we can see there are horizontal and vertical layers with higher surface temperature indicated existence of more intensive decomposition process. Second bunker silo is presented at Figure 12. where we can see a large number of small areas with higher temperature similar to Figure 7.

If we compare result of thermography measurement with results of basic chemical and microbial analyses (presented in Table 5., Table 6., Table 7. and Table 8.) we can say that there are connections. In Tables we can see, that values of samples with aerobic deteriorated silage are negative changed in most cases. The most problematic of silage quality are high values of pH (mainly values in Table 5., Table 7. and Table 8.), high values of molds and yeasts (mainly values in Table 5., Table 6., Table 7. and Table 8.). Generally worst results of monitored characteristics of samples from areas with higher temperature are presented in Table 8. (Lukavice location), where were pH 10.53, molds 9.43 (10log cfu · $g^{-1}$ of matter) and yeasts

10.81 (10log cfu · $g^{-1}$ of matter). This results are comparable with results published by (Liu, et al. 2013) where after 7 days of aerobic exposure of silage silo face were pH 7.58, molds 6.93 (10log cfu · $g^{-1}$ of matter) and yeasts 6.61 (10log cfu · $g^{-1}$ of matter). At the same time Figure 11 and 12 (Lukavice location) present thermograms with largest surface occurrence of deteriorated silage which confirms negative change of silage properties. Results of aerobic deteriorated silage of other samples are similar (Table 5., Table 6. and Table 7.).

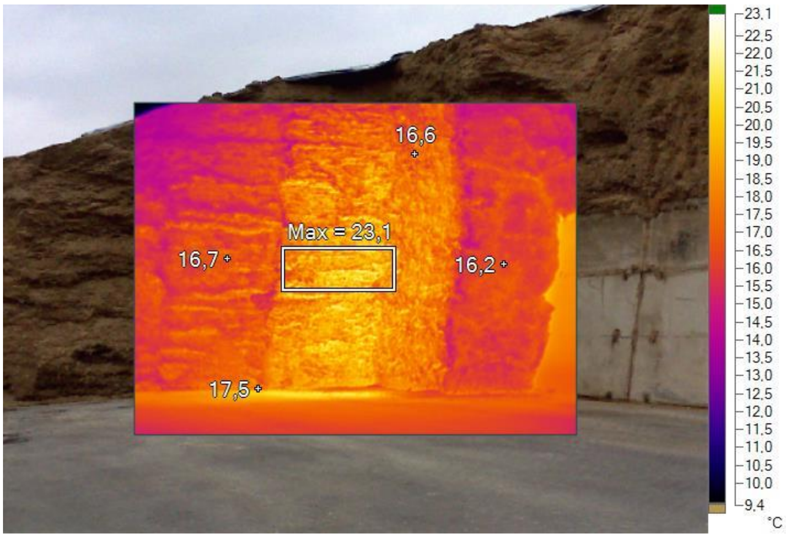


Figure 9. Thermogram of maize silage profile at Třeština location (part 1)

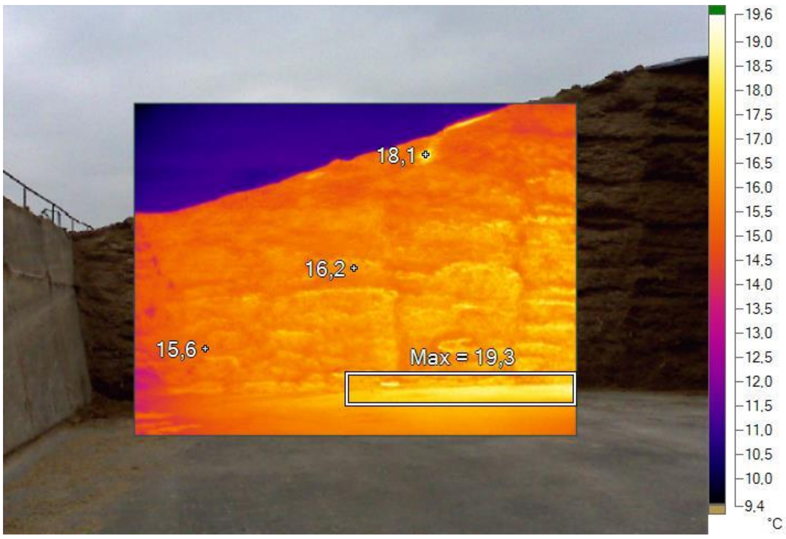


Figure 10. Thermogram of maize silage profile at Třeština location (part 2)

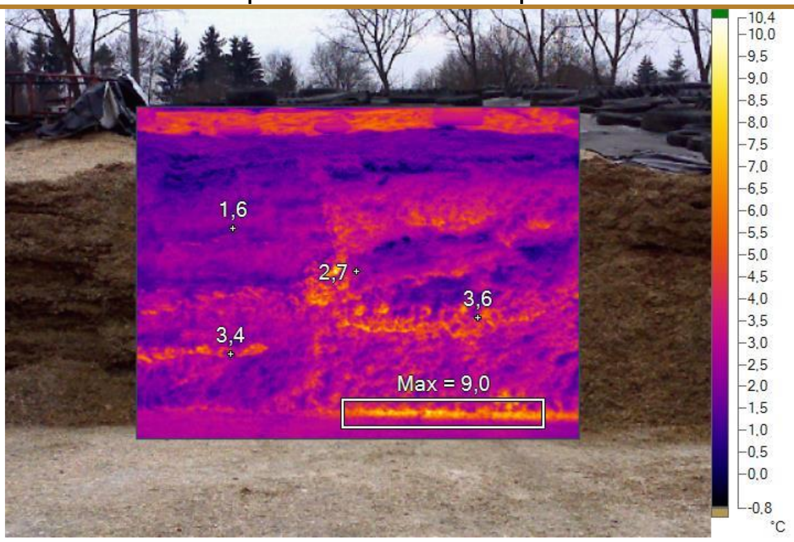


Figure 11. Thermogram of maize silage profile at Lukavice location (bunker silo 1)

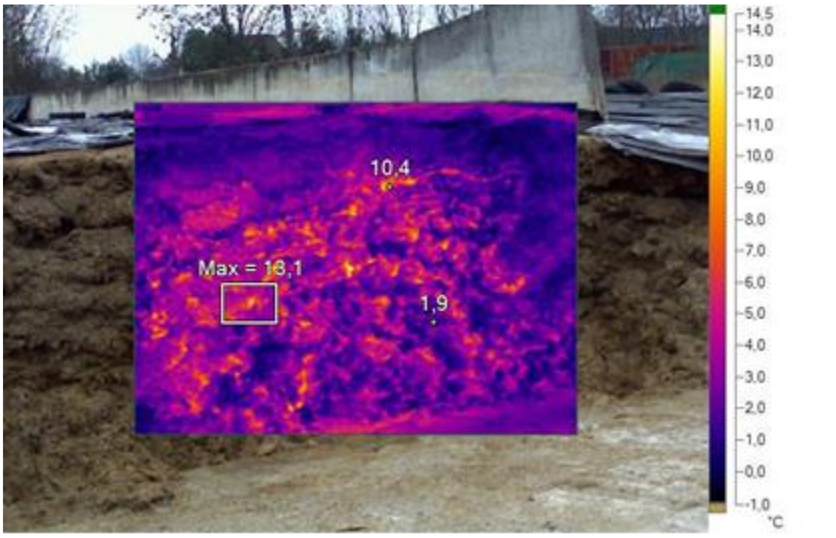


Figure 12. Thermogram of maize silage profile at Lukavice location (bunker silo 2)

Table 5. Main chemical and microbial comparisons of silage samples at two areas of silage profile with different temperatures (Klopina location)

| Item | Sample from area with low temperature | Sample from area with higher temperature |
|---|---|---|
| pH | 4.15 | 7.56 |
| Dry matter (%) | 23.7 | 28.4 |
| Lactic acid (% of DM) | 7.42 | 2.16 |
| Acetic acid (% of DM) | 1.24 | 0.27 |
| Ammonia nitrogen (% of total N) | 8.1 | 3.9 |
| Aerobic bacteria (10log cfu · $g^{-1}$ of matter) | 4.33 | 8.98 |
| Yeasts (10log cfu · $g^{-1}$ of matter) | <2.0 | 6.89 |
| Molds (10log cfu · $g^{-1}$ of matter) | <2.0 | 6.57 |
| Aerobic stability (h) | 0 | 96 |

Table 6. Main chemical and microbial comparisons of silage samples at two areas of silage profile with different temperatures (Švábenice location)

| Item | Sample from area with low temperature | Sample from area with higher temperature |
|---|---|---|
| pH | 3.71 | 4.79 |
| Dry matter (%) | 29.5 | 32.4 |
| Lactic acid (% of DM) | 4.52 | 1.01 |
| Acetic acid (% of DM) | 2.74 | 1.09 |
| Ammonia nitrogen (% of total N) | 5.61 | 3.82 |
| Aerobic bacteria (10log cfu · $g^{-1}$ of matter) | 2.62 | 7.1 |
| Yeasts (10log cfu · $g^{-1}$ of matter) | 3.11 | 6.84 |
| Molds (10log cfu · $g^{-1}$ of matter) | 1.72 | 5.21 |
| Aerobic stability (h) | 59 | 87 |

Table 7. Main chemical and microbial comparisons of silage samples at two areas of silage profile with different temperatures (Třeština location)

| Item | Sample from area with low temperature | Sample from area with higher temperature |
|---|---|---|
| pH | 3.64 | 5.7 |
| Dry matter (%) | 38.3 | 40.1 |
| Lactic acid (% of DM) | 3.82 | 1.57 |
| Acetic acid (% of DM) | 1.83 | 0.72 |
| Ammonia nitrogen (% of total N) | 9.96 | 7.95 |
| Aerobic bacteria (10log cfu · $g^{-1}$ of matter) | 6.64 | 10.37 |
| Yeasts (10log cfu · $g^{-1}$ of matter) | 5.53 | 7.64 |
| Molds (10log cfu · $g^{-1}$ of matter) | 3.14 | 6.32 |
| Aerobic stability (h) | 58.4 | 91 |

Table 8. Main chemical and microbial comparisons of silage samples at two areas of silage profile with different temperatures (Lukavice location)

| Item | Sample from area with low temperature | Sample from area with higher temperature |
|---|---|---|
| pH | 6.61 | 10.53 |
| Dry matter (%) | 33.8 | 35.7 |
| Lactic acid (% of DM) | 0.65 | 0.21 |
| Acetic acid (% of DM) | 0.4 | 0.12 |
| Ammonia nitrogen (% of total N) | 5.58 | 3.45 |
| Aerobic bacteria (10log cfu · $g^{-1}$ of matter) | 7.69 | 12.32 |
| Yeasts (10log cfu · $g^{-1}$ of matter) | 7.03 | 10.81 |
| Molds (10log cfu · $g^{-1}$ of matter) | 7.24 | 9.43 |
| Aerobic stability (h) | 0 | 7 |

## Discussion

If we compare results of infrared thermography with chemical and microbial properties of silage samples we can see connection. Analyzed samples from surfaces with higher temperature have negative changes of chemical and microbial properties (mainly values of pH, molds and yeast). When the estimated milk yields per megagram of harvested DM of corn silage were related to the mold count, it was noted that the loss of potential milk production occurred when the mold development exceeded 4 log cfu · $g^{-1}$ of matter, and it was almost halved when the mold count reached greater values then 8 log cfu · $g^{-1}$ of matter (Tabacco, et al. 2011). Our results confirm higher values of molds and yeasts in all samples of deteriorated silage. Maximal value is in case Lukavice location (Table 8.) where were molds 9.43 (10log cfu · $g^{-1}$ of matter) and yeasts 10.81 (10log cfu · $g^{-1}$ of matter). (Borreani and Tabacco, 2010) reported that the mold count could exceed 6 log cfu · $g^{-1}$ of matter in the peripheral areas of bunker silage, even when there were any visible moldy patches. The measured temperature of the silage in these areas shoved higher values then 40 °C, which exceeded those of the stable center of the bunker by more than 20 °C. Our survey confirms temperature differences between stable silage and aerobic deteriorated silage. Maximal temperature difference was 13.7 °C (Figure 6. – Lukavice location). According to the authors best knowledge, infrared technique as method for quick detection of silage decomposition process have not been deployed in a real size silage stack and therefore, a direct comparison between the results achieved in this study and results of other studies cannot be carried out. Partially conformable to our study is application of IR thermography techniques for measurement of temperature contour plot of an unsealed silage stack with detection of high temperatures close to a slit in the cover presented in (Laursen, 2005). Next is the study of temperature and oxygen concentration monitoring non-invasive wireless system which is presented in (Green, et al. 2012).

Some studies deal with modeling of ensiling process. Silage temperature variations after fermentation are a function of air and soil temperatures that can be modeled with using of finite element and finite volume methods. This modeling technique can be used for model heat and mass transfer in various applications for agriculture (Marra and Romano, 2002; Norton and Sun, 2006). (Ashbell, et al. 2002) states that silage temperature variation over time, prior to the decomposition process, should be modeled. Model would be useful not only to detect sealing failures but also to characterize silage performance when exposed to $O_2$, as the temperature history of the silage during anaerobic storage affects its aerobic stability. Influence of temperature and air velocity on ethanol emission from corn silage with the characteristics of an exposed silo face is presented in (Montes, et al. 2010).

## Conclusion

The results of the experiment confirmed possibilities for application of infrared thermography techniques for quick detection of surface temperature course in ensiling process Thermography technique is able to provide quick practice information about existing of intensive decomposition process causes aerobic deterioration of silage. This technique can be simple alternative for financially and technologically more exacting (but more accurate) wireless non-invasive sensor network.

## Acknowledgments

This paper was supported by project CZ.1.02/5.1.00/10.06433 Acquisition of instrumentation for BAT Centre at MENDELU AF in Brno for categories of food processing activities and categories of facilities for disposal or destruction of animal carcasses and animal waste.

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