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Assessment of risks in the field of safety, quality and environment in post-harvest line

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Abstract

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The objective of this work is the evaluation of threats in the field of safety, fire safety, quality and environment in the post-harvest treatment of grain, with an emphasis put on pre-cleaning and drying of grain. The paper describes the technology of pre-cleaning and drying of grain. Risks for individual machines were evaluated using a failure mode and effects analysis (FMEA), which is used to evaluate the threats in terms of fire risk, occupational safety, the effect of machine on the quality of final product, and effect on the environment. We have proposed measures and solutions to eliminate or minimise the consequences of threats. Risk rates are evaluated before and after measures adopted. It can be stated based on the results that risk was successfully reduced to an acceptable level after adopting measures.

Keywords: FMEA; fire safety; analysis of threats

In the production system of growing field crops, post-harvest treatment is at the end of the growing system where the yield of a specific crop is finalised. To preserve the quality of harvested materials, it is necessary to treat these materials according to their properties and purpose of use because they contain various undesirable impurities after being harvested as well as damaged and immature fruits, grains, and usually high moisture in terms of subsequent storage.

In connection with solving the fire safety of open technological equipment such as cleaners and dryers, similar conditions to those applicable to all the other structures shall apply. When using and operating such structures, there were currently revealed some particularities that must be treated during designing these structures (Pogran 2009). Practice shows that continuous changes in the structure of machines and in technologies of cleaning and drying bring new sources of fire risks. When working with machines in agriculture, it is possible to meet several aspects having an effect on safety. In addition to direct accidents on machines, there is often also dustiness, vibrations, etc.

Grain dust is generated during threshing and handling of grain. Exposure to other microbial components of grain dust, however, cultivable bacteria and fungi based on stationary air sampling were described in grain elevators (DeLucca et al. 1984; Góra et al. 2009) and grain terminals (Swan, Crook 1998), as well as in the animal feed industry (Smid et al. 1992). Personal exposure levels of total bacteria (viable and nonviable) and total fungal spores have been reported for grain farmers (Halstensen et al. 2007). Health effects resulting from grain dust inhalation may be

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more strongly associated with specific microbial components than to the dust level (Creasia et al. 1990; Douwes et al. 2003).

Studies of Halstensen et al. (2013) show the significance of microbial exposure in the grain industry. An improved exposure characterisation including several exposure components is needed in order to elucidate the associations between exposure and response. Even though the workers are exposed to a relatively low mean dust level, the microbial exposure may be high. Furthermore, the exposure levels of microbial components varied between workplaces although the dust levels were similar. It is recommended that exposure levels at different workplaces should be assessed separately and a task-based assessment should be done for detailed evaluation of efficient dust-reducing measures. The microbial content and knowledge of health effects of the microbial components should be considered in health risk evaluations of these workplaces. Sanders et al. (2013) clarified the method for determining the contamination of grains by dust pollution.

Reduction of airborne dust will therefore also reduce mycotoxin exposure, and several interventions against dust generation may serve this purpose. Further research is required to evaluate health hazards from respiratory grain dust and mycotoxin exposures. This should include short- and long-term dose-response studies of single and multiple mycotoxins, epidemiological studies and development of measurement methods for airborne mycotoxins, all of which may lead to the identification of safe levels for mycotoxin inhalation.

Respective types of risks that will occur may have an effect not only on the safety of operators but also on the quality of products and environment (Bujna et al. 2011; Korenko 2012; Bujna, Prístavka 2013). It may not be a sudden impact, but it may be gradual, arising when failing to observe basic rules, standards, laws, and the machine care system.

MATERIAL AND METHODS

Evaluating the risk rate of machines using the FMEA as a source of injury, fire, reduced quality of final product, and environmental hazard

(a) How the identified risks may contribute to injury, fire, reduced quality of final product, and environmental hazard? Who comes into contact with machines and why? It is necessary to consider the incorrect use, including the use of machines by untrained persons or persons at work-

Table 1. Decision table for the probability of threat occurrence with Failure Mode and Effect Analysis

Probability of threat occurrence		Score
Very negligible	it is improbable that threat occurs	1
Low	a low number of threats may occur on the component	2, 3
Moderate	threat of a lower extent may occasionally occur	4, 5, 6
High	frequent occurrence of threats may occur based on experience from the past	7, 8
Very high	it is almost certain that threats will frequently occur in a larger extent	9, 10

Table 2. Decision table for the probability of threat importance with Failure Mode and Effect Analysis

Probability of threat importance		Score
Insignificant	it is improbable that the threat would be a source of injury, fire, reduced quality of final product, and risk to the environment	1
Negligible	threat is negligible, it may cause injury, fire, reduced quality of final product, and risk to the environment only exceptionally	2, 3
Moderate	threat is evident, it may be a source of injury, fire, reduced quality of final product, and risk to the environment	4, 5, 6
High	system's functional capability is restricted (immediate repair is necessary), high probability of the source of injury, fire, reduced quality of final product, and risk to the environment	7, 8
Very high	very serious failure, safety risk, failure to comply with legal regulations, certain source of injury, fire, reduced quality of final product, and risk to the environment	9, 10

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Table 3. Decision table for the probability of threat detection with Failure Mode and Effect Analysis

Probability of threat detection		Score
Very high	functional failure or threat where causes are certainly detected	1, 2
High	detection of threat (its exposure) and its causes is very probable, it can be easily identified	3, 4
Moderate	threat exposure is easily identifiable, threat or its cause can be easily determined by inspection	5, 6
Low	detection of cause is less probable, threat exposure is not visible	7, 8
Very low	detection of threat/cause is impossible, component reliability is impossible to be confirmed	9, 10

Table 4. Criticality category with Failure Mode and Effect Analysis

Numerical value according to RR	Category	Consequences
1–60	negligible	no important system is damaged, minimum occurrence of sources of injury, fire, reduced quality of final product, and risk to the environment
60–120	marginal	no important system is damaged, there may be sources of injury, fire, reduced quality of final product, and risk to the environment
120–725	critical	sources of injury, fire, reduced quality of final product, and risk to the environment are evident, damaged equipment, dangerous situation
725–1,000	catastrophic	loss of system, injury, fire, reduced quality of final product, and risk to the environment

RR – risk rate

place. They are not only operators but also clearance personnel, safety workers, guests and the public.

(b) Organising the risks according to their importance. The assessment of risks is performed when potential damages resulting from the risk are multiplied by the risk exposure level. Considering that every accident may lead to injury, fire, reduced quality of final product, and environmental hazard, it is difficult to estimate potential damages. However, from several possible consequences, there will always be one more probable than the other. Therefore, it is necessary to consider all possible consequences, not only the most serious. The result of the risk assessment process is shown in the form of tables of various machine-related risks and the importance of every risk. In case of machine, it is impossible to determine a unified classification of risks; every risk must be assessed independently. However, importance may only be estimated because risk assessment is neither an accurate nor a finite process. It is an infinite cycle. The purpose of risk evaluation is to provide instructions to decrease risks. Risk evaluation is performed using Tables 1–4.

(c) Risk decreasing. Risk decreasing is defined within the meaning of elimination (Act No. 124/2006). The principle is that when the risk can be reduced, it must be reduced (STN OHSAS 18001:2009). It must always be given in context with economic reality. In these cases, regulations use the words such as "proportional'" indicating that some risks cannot be eliminated without unproportionally high costs. The risk assessment process is repeated – risks must be identified, quantified, and measures for their decrease must be suggested.

RESULTS AND DISCUSSION

Definition of grain pre-cleaner and dryer

Risks were evaluated in terms of safety, fire safety, the quality of work, and effect on the environment for the post-harvest line consisting of the following parts: grain pre-cleaner, grain dryer LAW SBC 13 LE (Quebec, Canada), elevators in the post-harvest line, and storage facilities. The grain drier LAW SBC 13 LE is equipped with a gas burner with a capacity of 400–4,300 kW. The burner is connected to the gas duct with an operating pressure of 35 kPa. The main closure of the gas burner is a spherical cock DN 125, located on the pipe DN 150, before the drier. The burner is automatically regulated by Honeywell EC 7850 (Morristown, USA). The performance of the drier is 13 t/hour.

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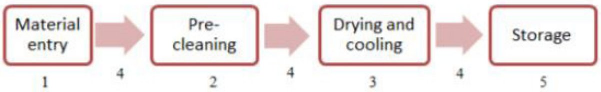

Fig. 1. Scheme of working procedures during drying

Risk assessment in terms of inbuilt technology

When assessing the technological processes in individual parts of equipment, it is necessary to analyse the sources of injury (according to STN EN ISO 12100:2011, threats are classified as: mechanical threat, electrical threat, thermal threat, threat by noise, threat by vibrations, threat by material and substances, ergonomic threat, threat related to the environment where a machine is used, a combination of threats) and sources of fire.

When drying plant products, also preparatory operations and material handling must be included in working procedures. Working operations are shown in Figs 1–3.

Before drying, material must be pre-cleaned in the pre-cleaner to remove impurities. Their presence influences the quality of drying. Material transport between operations is provided by various types of elevators. The drying process itself is performed in the dryer. To preserve the quality of dried grains, it is necessary to regulate the drying medium temperature, grain drying temperature, and drying time according to the moisture of dried material. The cooling of grains is the last drying stage in the dryer.

Individual locations of failures, possible consequences and measures are processed in Table 5.

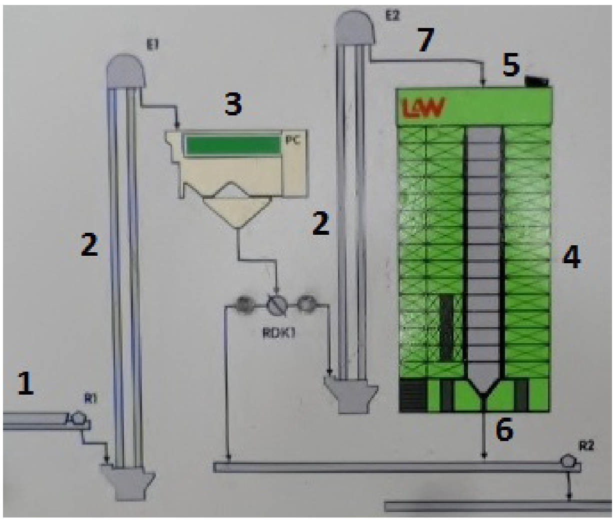

Fig. 2. Parts of the technological line for drying

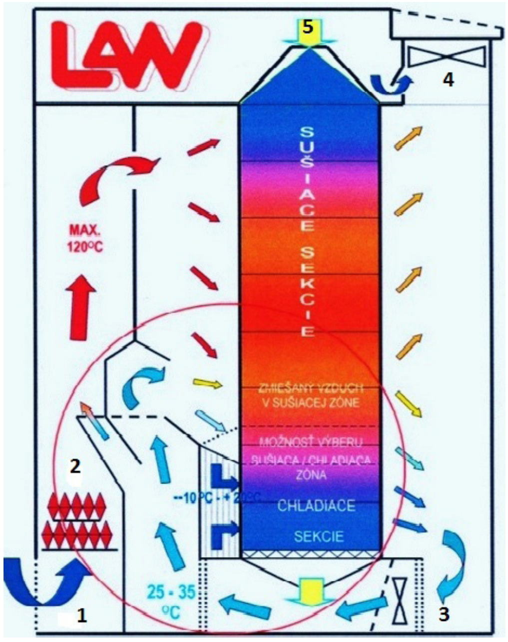

Fig. 3. Scheme of the grain dryer LAW

These locations are shown in Figs 4–9. Despite the fact that the line meets all legal regulations concerning fire safety and safe work, there can be seen many points that are a potential source of injury or fire.

Evaluation of FMEA

We were successful in significantly reducing the risk value on examined systems using the Failure and Effect Analysis (FMEA). After determining the importance, revealing the failure, and subsequent calculation of risk rate (RR), several conclusions have been drawn.

Table 5 contains several indicators showing high resulting risk values for individual components of the system examined. The highest risk rate was observed

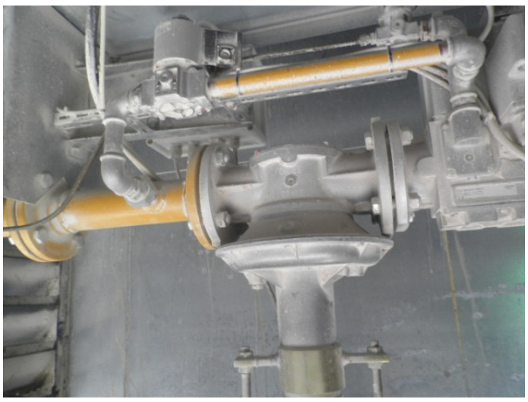

Fig. 4. Control elements of natural gas burners

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Table 5. Risk analysis in terms of safety, fire, product quality, and environment

No.	Failure location	Threat origin	Failure exposure	Failure cause	Possible consequences	B/P	Q	E	Occurrence	Importance	Detectability	Risk	Measures	Occurrence	Importance	Detectability	Risk
1	Belt elevator at entry	rotational parts	increased friction of elevator' cylinders to elevator's belt	incorrect tension of elevator's belt on mobile cylinders	overheating and increasing of temperatures in the point of friction	Y/Y	N	Y	3	8	6	critical (144)	checking the tension of belts at regular intervals	2	4	6	negligible (48)
2	Belt elevator at entry	rotational parts	seizure of supporting cylinders, friction of supporting cylinder to belt	damage to bearings on supporting cylinders of elevator	overheating and increasing of temperatures in the point of friction, belt wearing	Y/Y	Y	Y	6	8	4	critical (192)	checking the wear of bearings, lubrication of bearings at regular intervals	2	4	3	negligible (24)
3	Belt elevator at entry	overloading, short circuit, inactive parts	stopping, clogging, tearing of elevator	belt seizure, poor insulation, earthing	line stopping, damaged parts of line, fire	Y/Y	Y	Y	3	10	8	critical (240)	revision of electric equipment	1	8	8	marginal (64)
4	Belt elevator at entry, gearbox	mobility of component	damage to structure	damage to sealing, rupture of gear case	damage to bearings, seizure, fire	N/Y	Y	Y	6	8	8	critical (384)	checking the oil charge two times a year, oil change once a year	2	7	7	marginal (98)
5	Material trans port from entry to pre-cleaner; bucket elevator	mobility of component	damage to structure	damage to sealing rings; rupture of gear case	damage to bearings, seizure, fire	N/Y	Y	Y	6	8	9	critical (432)	checking the oil charge and oil tank leakage two times a year, oil change once a year	2	7	8	marginal (112)
6	Material transport from entry to pre-cleaner; bucket elevator	approaching of mobile part to fixed part	annoying sounds at workplace; seizure	insufficient tension of belt, entry of foreign object	bucket tear-off	Y/Y	Y	N	6	8	9	critical (432)	checking at regular intervals	2	8	7	marginal (112)
7	Material transport from entry to pre-cleaner; bucket elevator	hot objects	increased temperature of bearings	high load of elevator, incorrect maintenance of bearings	possible explosion in the upper part of elevator due to high dustiness of grains	Y/Y	N	Y	4	8	7	critical (224)	checking the wearing of bearings, lubrication of bearings at regular intervals	2	5	4	negligible (48)

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8	Material transport from entry to pre-cleaner; bucket elevator	mobile parts	increased damage to grain	worn elevator	increased dustiness	Y/Y	Y	Y	9	8	7	critical (504)	checking of wearing at regular intervals	2	8	7	negligible (112)
9	Material transport from entry to pre-cleaner; bucket elevator	access at maintenance	unavailable equipment in height	elevator structure	injury during maintenance, work in heights, covers of mobile parts	Y/N	Y	Y	6	9	3	critic al (162)	collective securing when working in heights and other protective aids	1	9	2	negligible (18)
10	Pre-cleaner	electric	destroyed connection cable	insulation is not according to standard	electrical shock, source of injury and fire	Y/Y	N	Y	5	8	8	critical (240)	checking or replacement of protectors for electricity distribution	1	8	6	nnegligible (48)
11	Pre-cleaner, drive of cleaning drum	mobile parts	increased temperature of bearings	high load of drum, incorrect maintenance of bearings	possible source of injury, fire	Y/Y	N	Y	6	8	6	critical (288)	checking the wearing of bearings, lubrication of bearings at regular intervals	2	7	5	mmarginal (112)
12	Pre-cleaner, drive of cleaning drum through V-belt	mobile parts	increased temperature	high load of drum, incorrect tension of V-belt, incorrect maintenance of bearings	thermal effect of mechanical energy, increasing of temperatures in friction point, possible source of injury and fire	Y/Y	Y	Y	7	8	6	critical (336)	checking the tension of V-belts at regular intervals	2	6	6	marginal (72)
13	Pre-cleaner	dustiness of processed material	dusty workplace, residues of processed material flying in the air	production process – cleaning, sorting, poor suction of fine waste	health problems with respiratory system	Y/Y	Y	Y	6	8	4	critical (192)	wearing of protective working aids – protective masks; checking the drive of fan for suction of fine particles, checking of cyclone	1	8	4	negligible (32)
16	Drive of bucket elevators for material transport to dryers; gearbox	mobility of component	damage to structure	damage to sealing rings, rupture of gear case	damage to bearings, seizure, fire	N/Y	Y	Y	6	8	9	critical (432)	checking the oil charge and oil tank leakage two times a year, oil change once a year	2	8	7	marginal (112)

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Table 5 co be continued

No.	Failure location	Threat origin	Failure exposure	Failure cause	Possible consequences	B/P	Q	E	Occurrence	Importance	Detectability	Risk	Measures	Occurrence	Importance	Detectability	Risk
17	Bucket elevators for material transport to dryers	approaching of mobile part to fixed part	annoying sounds at workplace; seizure	insufficient tension of belt, entry of foreign object	bucket tear-off	Y/Y	Y	N	4	8	6	critical (192)	checking at regular intervals	1	7	5	negligible (45)
18	Material transport from pre-cleaner to dryer; bucket elevator	mobile parts	increased temperature of bearings	high load of elevator, incorrect maintenance of bearings	possible explosion in the upper part of elevator due to high dustiness of grain	Y/Y	Y	Y	5	7	5	critical (175)	checking the wearing of bearings, lubrication of bearings at regular intervals	2	6	5	negligible (60)
19	Material transport from pre-cleaner to dryer; bucket elevator	mechanical	increased damage to grain	worn elevator	increased dustiness, explosion of dusty mixture	Y/Y	Y	Y	7	8	6	critical (336)	checking of wearing and correct function at regular intervals	3	7	6	critical (126)
20	Gravity elevator	electrostatic phenomenon	increased amount of static electricity due to friction	poorly earthed parts of elevator	ignition or explosion of dusty mixture	Y/Y	Y	Y	3	8	6	critical (144)	conductive connection of all metallic parts, regular inspection of earthing	1	8	5	negligible (40)
22	Drying section	electric	failure to shut the dryer down in case of overheating above 100°C	failure of thermal sensors	explosion of dusty particles of grains	Y/Y	Y	Y	7	8	9	critical (504)	regular inspection of thermal sensors	2	8	8	critical (128)
23	Dryer, air heating by gas	electric	sensor body contact	poor quality protection	damage to sensor protection, source of explosion, injury	Y/Y	N	Y	4	7	7	critical (196)	regular specialised inspections	2	7	7	marginal (112)
24	Dryer, air heating by gas	electric	damaged sensors due to environment	insufficiently covered sensor	increased temperature, initialiser of fire, injury	Y/Y	N	Y	7	8	9	critical (504)	regular maintenance	2	7	6	marginal (84)

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25	Dryer, air heating by gas	thermal	increased maximum permissible temperature of dryer	emergency thermostat does not send a failure signal to PC	exceeding the max. temperature 300°C, grain ignition	Y/Y	Y	Y	5	8	9	critical (360)	regular testing of equipment capability	2	7	7	marginal (112)
26	Fan of cooling air	due to effect of environment	clogging of electric motor on fan	high dustiness of environment	destruction of electric motor, overheating, ignition	Y/Y	N	Y	4	7	5	critical (140)	regular cleaning and filtration of air entering into fan	4	7	3	marginal (84)
27	Dryer, removal of moist air	due to effect of environment	condensation of water vapour on instruments	non-functional fan of vapour removal	short circuit on electric equipment, fire, injury	Y/Y	N	Y	6	8	7	critical (336)	regular inspection of fan for vapour removal	3	6	6	marginal (108)

B/P – safety/fire safety; Q – quality; E – environment; Y – yes; N – no

Fig. 5. Pre-cleaner with dryer

in the drying section – failure of temperature sensors, which is the most important element in drying regulation. The corrective measures in Table 5 provide possibilities how to avoid individual failures.

Table 5 contains system's components with risk number before and after adopted the measures. We can see how the risk value on individual system's parts has decreased. The risk value decreased by about a half and this value can be considered as a controllable risk. A high risk rate before measures can often be reduced by the regular maintenance of system's components, by changing the organisation and qualification of personnel.

In our case, failures with the risk number of the category critical failures before measures represent 96% of the total possible components on which failures of a certain extent may occur. After adopting corrective measures, 43% got into the category negligible failures because their values do not exceed the risk number 60 when observing the measures, which may be considered great success during practical application.

In the past, especially the pre-seasonal maintenance was used in the company, and repairs were done when a failure occurred. Also some of the suggested measures were performed during

Fig. 6. Removal of fine impurities (dust) in cylinder pre-cleaner (cyclone)

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Fig. 7. Covers of mobile parts on pre-cleaner

Fig. 9. Drive of bucket elevator (electric motor without cover)

the pre-seasonal maintenance but the FMEA has shown that it is insufficient because actions depend on the amount of material processed on the line during a year, which depends on the yield in the given year and on the amount of cleaning orders for other farmers. Based on the suggested measures (Table 5), the maintenance plan was prepared for this line. For maintenance and OHS, we created the system functioning based on exact dates of specialized checks, maintenance and trainings. The plan contains responsible persons and the subsequent system of verification of satisfied (unsatisfied) instructions. Based on this system, the company is able to more dynamically respond either to changes on the line or to changes in the EU legislation.

The most important issues implemented in the field of OHS:

– inspection and repair of fixing and integrity of covers on all the parts of the line ensuring reduced noisiness and dustiness on the line;

Fig. 8. Position of bearings on pre-cleaner and grease cup points

– inspection of rotational parts on all the parts of the line ensuring reduced vibrations on the line;
– added barriers to secure collective work in heights;
– protection from vibrations – operators have shoes with anti-vibration slip sole;
– protection from dustiness – operators have protective mask, and the amount of dust and subsequent mycotoxins are reduced by filtration of fine particles;
– protection from noisiness – operators have air protection.

It may be stated that using the FMEA has a positive effect on safety, work quality, and increasing the line's reliability, but a correct organisation of work and motivation of people are necessary.

CONCLUSION

This work solves the comprehensive risk analysis using the FMEA in terms of safety, fire, the quality of product, and environment in the post-harvest treatment of grains. The performed analysis of the quality of work and working environment of the examined post-harvest line gives the answer to what the shortcomings in the constructional solution, technology of work, structure of machines and their working regimes are.

Using the FMEA appears to be a correct response to increasing the safety and quality and reducing the potential impacts on the environment. The implementation of FMEA leads to increasing the overall productivity of work and reducing the load of workers. We know that the current market is enriched by increasingly complex machines and

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technologies, which increases the probability of failures and new threats; therefore, increased attention should be paid to occupational safety and health. Employers are responsible for the concept and policy of occupational safety and health. To increase the overall efficiency of using systems, workers must be instructed in possible failures on these systems. The application of FMEA can prevent problems frequently occurring especially with new technologies.

Based on FMEA, the line owner is able to elaborate the system of repairs and maintenance on specific equipment and to detect many points that are a potential source of injury, fire and reduced quality of product (Table 5). The owner may decide which fire protection will be used to prevent fire spreading in the premises of pre-cleaner and dryer, whether the amount of flammable substances will be reduced, whether dust will be removed from the premises of pre-cleaner, whether dusty particles will be separated in cyclones and specially stored, or a combination of both.

An important criterion is reducing the risk of ignition of flammable substances by the integrity of technology covers protecting from in-leak and moisture formation, by checking and maintenance of rotational parts of electric and transport equipment, by permanent functionality of instruments for moisture measurements and temperatures of dried product (Table 5), and by observing the prohibition of using open fire and smoking in locations with increased fire risk.

Within prevention, organisational and technical measures are ensured by permanent supervision of the operation of technological equipment and its components, by observing the regime of production activity in individual parts of technology, by verifying the meeting of regulations, and by personnel's ability to perform preventive fire activities and activities in case of a dangerous event.

To successfully eliminate the risk in post-harvest treatment, it is necessary not only to identify the risk and propose safety measures but also to ensure their subsequent and permanent inspection. They are employees who must realise that the maintenance of technical equipment and using protective working aids is not only employer's requirement to meet legal regulations but it is also health protection from occupational injuries and diseases.

Every employer must remember that by continuously building the awareness of employees concerning occupational safety and regular maintenance, they can achieve not only the saving of costs but also saving the lives of employees who are the most important part of every company.

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