Selected Problems of Goods Warehousing

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This article contains information related to selected factors affecting the warehousing of goods. Physicochemical parameters such as temperature, humidity, sunlight, air that have influence (positive or negative) on the goods and people in the warehouse are identified. The next part of the article presents devices for measuring and controlling the listed parameters, with special emphasis on the CO_2 and oxygen.

Keywords: warehouse, temperature, humidity, sunlight, air, warehousing, inertization, measurement.

1. INTRODUCTION

The European and national standards regulating goods warehousing require the environment in which they are stored to be managed. Temperature, humidity, sunlight, and air are the primary factors that influence not only warehouse workers but also the quality, value, life, and suitability of the warehoused goods. The influence may be positive or negative. With this in mind, issues connected with ensuring proper warehousing environment have become the focus of analyses that also take the role of management into account.

Theoretical (analysis, synthesis, comparison) and empirical (observation, opinion surveys) were employed to test the following hypothesis: *identification of physicochemical parameters and their systematic monitoring have an influence on the storage conditions of goods in a warehouse.* The study was performed at three warehouses: Frigo Logistics in Radomsko (storage of food products at temperatures below 23°C), JYSK - main warehouse for the Eastern European market (home and garden goods), Kilagro ice cream warehouse (300 tonnes of ice cream are manufactured daily at the company's two plants: in Chechło Pierwsze near Pabianice and in Kalisz).

2. PRIMARY FACTORS INFLUENCING THE QUALITY OF GOODS DURING STORAGE

Many different products are stored in warehouses. The Polish Classification of Goods and Services (PKWiU) organizes them into the following classes[1]:

- A – products of agriculture, forestry, hunting and fishing, which include crops and plant products, live animals and animal products, products of forestry, logging and related services, fish and other fishing products;
- B – products of mining and quarrying, which include − coal and lignite, crude petroleum, natural gas and its by products such as ethane, butane, propane; native sulphur, other products, e.g. stone, sand and clay, peat, salt and pure sodium chloride, bitumen and natural asphalt, precious and semi-precious stones, and sea water;
- C – manufactured products, which include[2]:
  - ✓ food products, including prepared meals and dishes,
  - ✓ textiles,

[1] See Regulation of the Council of Ministers of 4 Sept. 2005 on the Polish Classification of Goods and Services (PKWiU).

[2] Only those Class C goods that were actually stored at the studied warehouses are listed here.

- ✓ leather, tanned and dressed leather products,
- ✓ wood and products of wood and cork, articles of straw and plaiting materials,
- ✓ paper and paper products,
- ✓ fabricated metal products,
- ✓ rubber and plastic products,
- ✓ non-metallic mineral products, including glass and glass products, refractory products, ceramic construction goods, articles of cement, concrete and plaster,
- ✓ electronic products,
- ✓ electrical equipment, including electric motors, electric lighting equipment,
- ✓ domestic appliances, electric and non-electric,
- ✓ furniture.

Activities performed at the warehouse have also been grouped. The groups have been named and codified. Below are a few examples:

- 52.10.11 – warehousing and storage of frozen and refrigerated goods[3];
- 52.10.12 – bulk liquid or gas warehousing and storage;
- 52.10.13 – grain warehousing and storage;
- 52.10.19 – warehousing and storage of other goods.

When the classification referred to above is analyzed, it becomes evident that goods differ with regard to their construction, purpose, physical and chemical properties, and therefore, they require different handling, transport and storage.

Temperature, air, humidity and sunlight are among the most frequently listed factors that affect the quality of goods during storage.

Temperature plays an important role in microbial growth, maintaining selected physical properties of stored goods, and controlling the rate of chemical reactions that they undergo. Excessively high temperatures lead to rapid dehydration, loss of flavour, and change in texture of many products. It may intensify bacterial growth and cause food spoilage. Temperatures below 0°C are harmful to products with water content because as the water freezes it not only damages the packaging but also the product itself. Some products are sensitive to low temperatures (e.g. potatoes, fruit). As a result of overcooling, they lose flavour and become unsuitable for consumption. Rapid changes in temperature are also undesirable as they cause water vapour to condense on products and their packaging[4].

Humidity has a rather significant influence on the quality of goods stored in warehouses. Insufficient humidity leads to the drying of stored products, shrinkage of raw materials, excessive volumetric reduction and loss. The air that contains too much moisture may cause agglomeration and lumping of products; it may bring about changes in product appearance, lower the quality of the packaging as bags come apart and tins rust. Indirectly, humidity has a negative effect on stored food as it provides favourable conditions for microbial growth.

Electronic devices are also sensitive to humidity. Moisture condensed on e.g. connectors promotes formation of oxides. As a result, conducting properties deteriorate and the flow of electric current is hindered.

Air has a significant influence on many stored goods such as eggs, flour, groats, rye grain, fruit, leather, electronics, and metal products. The influence may be positive or negative as the following examples illustrate[5]:

- Foods that share properties of living organisms categorically require continuous supply of air and ventilation to maintain respiration processes. Shortage of fresh air is a cause of cellular death and rapid decay of raw materials. This group of foods includes: grains, potatoes as well as some other vegetables and fruits. For this group of products, insufficient air supply results in increased temperature of the product due to intensified respiration process. As heat is released in the process, rapid spoilage ensues.
- Oxygen in the air is chemically reactive, which may result in unwanted changes in the taste and smell of products especially if they contain even the smallest amount of fat. Air accelerates the process of lipid oxidation and oxidative rancidification. Adverse effect of air can also be observed for fruit and vegetable storage.
- Air may also contain contaminants e.g. nitrogen oxides, hydrogen sulphide. These

[3] Groups: 52.10.1 and 52.10.12 constituted inventory in the studied warehouses.

[4] See: *Czynniki wpływające na jakość przechowywanych towarów*, http://eraumts.com.pl/, (accessed on 12 March 2017).

[5] See: *Czynniki obniżające jakość towarów - Czynniki atmosferyczne i inne warunki otoczenia*, http://www.eduteka.pl/, (accessed on 15 March 2017).

compounds affect the intensity of the processes of corrosion of metal products and they also cause damage to structures and machines[6].

Sunlight is a factor which operates bi-directionally. On one hand, sunlight activates enzymes which are instrumental in optimal ripening of e.g. fruits, vegetables and sprouts, which, of course, is beneficial. On the other hand, however, whenever we deal with products that contain fat, sunlight will contribute to its rancidification.

Sunlight also has an adverse effect on the vitamin content in foods: milk, after six hours' exposure to sunlight, will lose about 66% of its vitamin B_2 content[7].

To facilitate protection against light, modern warehouses are often windowless and only artificially lit.

3. INSTRUMENTS FOR MONITORING AND CONTROLLING OF ENVIRONMENTAL CONDITIONS IN WAREHOUSES

Depending on the kind of stock, a warehouse needs to have adequate infrastructure to ensure:

- proper workplace environment for its workers in compliance with occupational safety and hygiene requirements;
- proper conditions for goods storage to avoid deterioration of properties and parameters.

Such conditions can be ensured when the following are met:

- technical requirements relating to the height, area, lighting, fire safety systems, evacuation routes, walls, flooring, doors, sanitary facilities, etc.;
- hygiene and sanitary standards relating to temperature, humidity, presence of certain gases, ventilation, air conditioning[8].

2.1. HUMIDITY MEASUREMENT

Humidity affects physical and structural properties, suitability and quality of some goods stored in warehouses. These include:

- food and food products;
- pharmaceuticals;
- building materials;
- selected chemical products;
- selected home appliances.

Humidity promotes the growth of bacteria, fungi and moulds which have an adverse effect on food products and pharmaceuticals in particular, as well as on the health of workers. Humidity is also the source of disadvantageous chemical reactions (this relates to e.g. petrochemical products, natural gas, technical gases). It accelerates corrosion and has a negative impact on electric and electronic devices (moisture condensed on alloy connectors brings about oxide formation, as a result of which the connectors lose their conductivity).

However, it is important to remember that ensuring proper humidity of air (by humidification) is beneficial for electronic products because[9]:

- it provides protection against electrostatic discharge (ESD);
- it bolsters the lifespan of electronic components and subassemblies;
- semiconductors gain additional protection against failure;
- dusting and dust attraction are reduced;
- energy cost is reduced with high pressure humidification;
- thermal comfort is increased with adiabatic cooling[10];
- workplace comfort is improved.

Humidity measurement is performed with instruments that generally can be grouped into hygrometers (relying on changes in properties of specific substances that result from a change in

[6] See: Drzewiecka K., *Czynniki naturalne wpływające na przechowywanie towarów*, „Logistyka", 4/2010, p. 34.

[7] See: P. Brodowska, *Co wpływa na jakość przechowywanej żywności?,* http://www.zdrowieintymne.pl/, (accessed on 12 March 2017).

[8] Pursuant to the provisions of the Regulation of the Minister of Infrastructure of 12 April 2002 on the technical condition of buildings and their location, ventilation and air conditioning systems should ensure proper quality of the indoor environment including the required air change rate, air cleanliness, temperature, relative humidity, air speed in compliance with specific regulations and requirements of the Polish standards concerning ventilation, fire safety, and acoustics as laid down in the Regulation.

[9] See: *Produkcja elektroniki a nawilżanie powietrza*, http://www.draabe.pl/, (accessed on 12 February 2017).

[10] Adiabatic cooling relies on the process of water evaporation where sensible heat (temperature) is transformed into latent heat (humidity).

humidity of the examined system) and psychrometers (consisting of two thermometers - a cold-bulb and a dry-bulb thermometer - where the mercury bulb of one of them is sheathed in a wet wick).

There are the following types of hygrometers:

- absorption hygrometers – humidity measurement relies on measuring the absorption of water vapour from the air by an absorbing material and determining the value of absolute humidity[11] (it is a complex and complicated method used for calibration and in laboratory measurements);
- condensation principle hygrometers – humidity is determined indirectly based on the measurement of the dew-point temperature;
- hygroscopic hygrometers – measurements rely on humidity-induced changes in specific properties of physical bodies (e.g. human or animal hair);
- electric (electronic) hygrometers – measurements rely on changes in resistance or conductivity of mineral and other materials according to humidity(they consist of an electronic sensor, an electronic measurement component, and a display where the humidity readings are displayed.

Each type of the hygrometer has its advantages and disadvantages some of which are discussed below.

Hair hygrometers are reliable, simple and inexpensive. However, with the measurement error ranging from 5 to 7%, they are rather inaccurate.

Electronic hygrometers are characterised by a high accuracy of measurements and ability to monitor other properties of the air e.g. temperature. They can also perform around-the-clock measurements and signal with a sound alarm whenever humidity and temperature deviate from the preset permitted values. Some models of the hygrometer can control air humidifiers/air-dryers. Disadvantages of the electronic hygrometer include the need to supply power, relatively high cost and, in the case of less expensive models, unreliability[12].

Moisture content measurement is carried out in a different manner for dry materials and goods. Physical phenomena are exploited in their case. In practice, four methods of measurement are used (Fig. 1)[13].

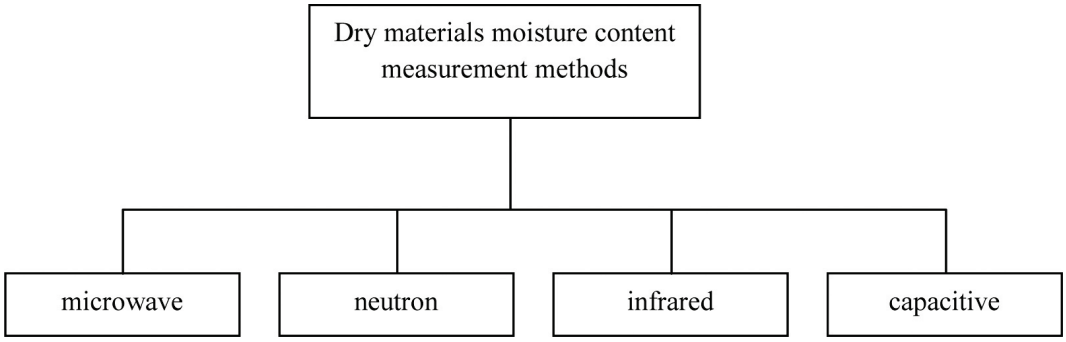

Fig. 1. Dry materials moisture content measurement methods.
Source: own study.

The first method. Moisture content of dry, non-conductive materials (e.g. coal) can be determined with contactless microwave measurement method.

The basic version of the system consists of a radiometric measuring path which comprises a control unit, a transmitter and receiver antennas, and cables connecting the antennas with the control unit. The microwave signal emitted by the transmitter antenna travels through the measured product to the receiver antenna. While it travels

[11] Humidity is expressed as relative (the ratio of the actual mass of the water vapour in a specific volume of air and the mass of the water vapour that it could hold when saturated at the same temperature)and absolute (the mass of water vapour in a unit volume of air).

[12] See: Trela B., *Co to jest higrometr i jak działa?*, http://www.rosliny-owadozerne.pl/, (accessed on 28 February 2017).

[13] See: Wąsowicz S, Wyrwich M., *Pomiar wilgotności materiałów sypkich 3 różne metody*, http://www.podkontrola.pl/, (accessed on 01 March 2017); *Wilgotność materiałów sypkich – czym mierzyć?*, http://www.akademia-automatyki.pl, (accessed 01 March 2017).

through the product, two phenomena occur: attenuation and phase shift of the signal.

LB 456 is one of the devices for continuous non contact measurement of moisture content in dry products (non-conducting) such as coal, wood chips, limestone, gypsum, etc.

The second method. Neutron measurement relies on hydrogen atoms slowing down fast neutrons. As they collide with the nuclei of hydrogen atoms, fast neutrons become thermalized. The higher the moisture content, the more fast neutrons become thermalized and consequently the meter readings show higher count of slow neutrons.

LB 350 is an example of measuring instruments that utilize the described neutron phenomenon. It is used for continuous contactless measurement of moisture content in dry products such as: coke, ore, and sand.

The third method (employed in the studied warehouses). NIR (NIR – *Near Infra Red)* moisture measuring instruments rely on the phenomenon of absorption and reflection of infrared waves by materials. When the amount of the reflected infrared radiation and the properties of the material (relation between absorbance and reflectance) are known, it is possible to determine the water content of the product or, in other words, its moisture content. It is a non-contact method and makes it possible to measure moisture content of paper, cardboard, carton, food products among others.

NIR - 6000 moisture analyzer is one of such instruments, which is used primarily for measuring the humidity of materials in the production process, quality control of finished products, and control of the processes of drying.

The fourth method. Capacitive measurement relies on measuring the relative permittivity (dielectric constant) of dry materials, which determines their humidity. It is the simplest, most economical method used in real time humidity measurement of sand, quartz sand, lime, gravel, ore, sewage sediment, grains, concrete aggregate, biomass (sawdust, straw, wood chips), rice, gypsum, clay etc. The method is most frequently used on conveyor belts and screw conveyors, although it is also applied in gravitational chutes.

MMS type devices can serve as an example of the instruments described above. They are used for measuring moisture content of any kind of substances with granularity equal to or below 7 mm or semi-liquid on conveyor belts, pipes/channels and tanks. The working surface of the sensor can be made of thermoplastic, ceramic materials or Teflon. The thickness of the measured layer (the measuring depth) is ca. 150 mm[14].

2.2. TEMPERATURE MEASUREMENT

In warehousing, temperature is one of the critical parameters that affect the quality, suitability and marketability of products.

Thermometers are used for measuring this quantity, which, depending on the physical property that they rely on, are divided into[15]:

- expansion thermometers that include: gas, liquid, pressure-liquid, pressure, vapour, relying on the expansion/contraction of solids;
- electric: resistance, thermocouple, semiconductor, piezoelectric;
- optical;
- specialized and others.

Expansion thermometers rely on changes in the volume of the thermometric material caused by a change in temperature. Solids, liquids and gases can be used as thermometric materials. If the relation between the volume of a thermometric material and its temperature is known then, based on the measured change in volume, it is possible to infer the temperature change. In practice, the elements that measure changes in the volume of the thermometric material are directly calibrated into degrees Celsius.

Electric thermometers operate based on the influence of temperature on electric properties of the materials that sensors are made of or on temperature-dependent change in the electric potential difference at contact points of various materials.

Currently, pyrometers, which measure the temperature of the surface of an object, are the most commonly used temperature measuring instruments. The pyrometer analyzes thermal radiation emitted by the object whose temperature is to be measured. To improve the ease of use and accuracy of measurements, the device is fit with a laser pointer to facilitate precise aiming at the measured object. It is a non-contact infrared thermometer in a compact casing in the shape of a gun. The measurement is performed by aiming the device at the object and pressing the button on the

[14] See: *Mierniki wilgotności serii MMS*, http://www.introl.pl, (accessed on 22 March 2017).
[15] Karczewski M., (2007), *Laboratorium termodynamiki technicznej*, WAT, Warszawa, p. 5.

pyrometer. It is especially useful for measuring the temperature of the surface of objects that are extremely hot (up to 1300°C), dangerous, inaccessible, moving or fixed.

2.3. OXYGEN MEASUREMENT

Oxygen is used in many technological processes, for example during combustion (burning) and oxidation. However, for other activities, its presence may be disadvantageous or, in some circumstances, even dangerous. In modern warehouses, the oxygen concentration level in the air is lowered to reduce the risk of fire. Therefore, it seems critical that oxygen levels should be continuously monitored to enable adjustment and ensure that technological installations are protected.

Measurement techniques used for oxygen level monitoring are based on various measurement principles. Methods that rely on the magnetic properties of oxygen, electrochemical and zirconia cells are the most common. Suitability of these measurement instruments depends on a number of different factors including the type of gas to be measured, temperature, pressure, installation or environmental conditions.

LB-905 is one of the instruments used for measuring the concentration of oxygen in the air that uses the flow method. The measured gas is supplied to the O_2 oxygen meter through stub pipe connectors that enable the incorporation of the oxygen meter into the system of tubes that sample the air from the monitored area. The flow of the gas should be forced with e.g. an air pump. Measurement readings are transmitted through an interface, which is the principal way measurement devices are connected in the LAB-EL systems.

The interface can use any line assembled of two conductors which can be arbitrarily polarized and which simultaneously transmit data and electrical power over large distances (measurement range of up to 1000 m).

Oxygen meters are used in the warehouse fire prevention system which relies on the reduction of oxygen concentration (nitrogen inerting system[16] – SZA). The inerting system employs controlled reduction of oxygen concentration with a non-reactive (inert) gas - in this case, nitrogen. Reducing (usually from 21%[17] to 15%) and maintaining the content of oxygen on an appropriate, safe level prevents goods stored in the warehouse from igniting.

The SZA consists of[18]:

- a nitrogen source - nitrogen generator(s);
- a nitrogen injection system(nozzles, valves, piping);
- an electrical system, control and measurement equipment(oxygen meters, carbon dioxide sensors, thermometers, humidity analyzers);
- information and warning systems (warning plates, sound and light warning devices, LED displays, oxygen concentration key switches, etc.);
- the main switchboard and operator control panel.

2.4. CARBON DIOXIDE MEASUREMENT

CO_2 concentration measurements are performed with specialized sensors, which operate based on specific measurement methods. The most common sensors include[19]:

- electrochemical sensors – operation relies on the reaction between the sensor's two electrodes ; one of them is a reference electrode, whereas the other is the measurement electrode whose potential depends on the carbon dioxide concentration;
- infrared sensors of two primary types:
  - ✓ photo-acoustic – the principle of operation: 1) a gas sample is injected into the measurement chamber and exposed to pulsing infrared radiation of specific wavelength, 2) if the sample contains the measured gas, it will absorb the infrared radiation in the amount that is proportional to the gas concentration, 3) gas molecules heat up and cool down as they absorb the pulsing infrared radiation energy,4) changes in the pressure resulting from the heating up and cooling down of the molecules are measured by a sensitive

[16] Nitrogen is one of the main components of air. It is a non-reactive, colourless, odourless gas. It is not toxic. Its density is similar to the density of the air. It does not conduct electricity and it readily disperses in the confined space to be protected, which renders it perfectly suitable for fire prevention applications.

[17] The air in the surrounding environment contains by volume 78% nitrogen, 21% oxygen and 1% trace gases.

[18] *System redukcji tlenu*, http://pmgpl.com.pl/, (accessed on 04 March 2017).

[19] See Szuba P., *Pomiar dwutlenku węgla, a układy klimatyzacji i wentylacji*, http://www.podkontrola.pl, (accessed on 28 February2017).

microphone located inside the photo-acoustic infrared monitor,

- ✓ non-dispersive infrared absorption (NDIR) – operates on the principle of infrared radiation, which, in a narrow range of its wavelengths, is absorbed by the carbon dioxide. Part of the radiation energy is absorbed by the measured gas, while the remaining part reaches the detector (by using a filter, it is possible to make sure that no other gas but carbon dioxide is detected).

One example of the meters described above used for measuring the concentration of carbon dioxide is the LB-852 device with analogue voltage output 0.10 V and a digital electric interface. The device requires an external power supply source. The gas whose concentration is measured is supplied to the CO_2 meter through stub pipe connectors. The flow of the monitored gas should be forced e.g. with an air pump. The interface allows the meter to be connected to other systems e.g. room climate control units, data loggers. The LB-852 has an auto-calibration function (the function requires that fresh air be supplied to the meter while it is in operating mode at least once a week[20].

2.5. ILLUMINANCE MEASUREMENT

Light is one of the primary factors influencing the comfort of the work environment, the wellbeing and safety of people working in confined spaces.

Light can also be an agent of many changes affecting raw materials, e.g. vitamin decay, changes in fats, discolouration – and therefore, it is one of the cardinal and most frequently measured values. When light is analysed, illuminance[21] is measured and its values are expressed among others in the SI system lux units.

In simple terms, illuminance is the amount of light which - emitted from the source and reflected off various 'obstacles' (walls, furniture, structural elements, etc.) -reaches a specific point in space. Illuminance levels recommended for different types of spaces and activities are specified in many norms.

There are many distinct light intensity meters available in the market. One of them is the LB-900 device. The device comprises a microprocessor measuring system and an integrated radiation sensor – a silicon photodiode; it is a small size externally powered stationary device.

The LB-900 light meter takes advantage of the built-in silicon photodiode. Light is measured by a high precision analogue-to-digital converter. On the basis of the voltage measurement from the integrated radiation sensor and the digital calibration values logged in the device memory, the converter's microprocessor computes the result of the illuminance measurement.

The light meter (light intensity meter, photometer) is equipped with a digital interface for data transmission (its timing is compatible with the RS-232C standard).

Through the interface, the meter can be connected to any registration system (data acquisition), e.g. via a converter to any PC or weather station, which enables remote and automatic acquisition of readings from the radiation sensor of the meter[22].

4. CONCLUSION

The study carried out at the three warehouses confirmed the hypothesis '*identification of physicochemical parameters and their systematic monitoring have an influence on the storage conditions of goods in a warehouse'.* Based on observation, opinion surveys and interviews with experts it has been established that modern systems of environmental monitoring operate at the warehouses, which facilitates warehouse climate management in accordance with regulatory requirements. The implemented technical systems strictly comply with the requirements specified in national and international documents.

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[20] *Miernik CO2, pomiar stężenia dwutlenku (ditlenku) węgla LB-852,* http://www.label.pl/, (accessed on 28 February 2017).

[21] Illuminance is the amount of light falling onto a surface, measured at a specific point.

[22] See: *Światłomierz, luksomierz, fotometr - miernik promieniowania słonecznego LB-900*, http://www.label.pl/, (accessed on 28 February 2017).

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LAWS AND REGULATIONS

[1] Regulation of the Minister of Infrastructure of 12 April 2002 on technical matters, their buildings and their location
[2] Regulation of the Council of Ministers of 4.09.2015 on the Polish Classification of Products and Services (PKWiU)

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