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INFLUENCE OF THE WASTE GLASS USES ON THE CEMENT MORTAR PROPERTIES

WPŁYW STOSOWANIA SZKŁA ODPADOWEGO NA WŁAŚCIWOŚCI ZAPRAWY CEMENTOWEJ

Przemysław Czapik*, Dominik Kuza, Michał Boroń
Kielce University of Technology, Poland

Abstract

In this paper the influence of waste glass on the properties of cement mortar was described. The coloured waste glass in two different forms was used: the glass cullet with a particle size of 0.125-4.00 mm as a fine aggregate and the glass powder with a particle size below 0.125 mm as cement replacement. Both types of glass were obtained by crushing and milling brown glass bottles. The tests were carried out on mortars in which sand was entirely replaced by glass cullet or 20% of cement was replaced by glass powder. The effect of glass cullet and glass powder on the properties of cement mortar, such as setting time, consistency, flexural and compressive strength was determined. Moreover, the role of glass cullet as a potential source of expansion resulted from the alkali-silica reaction was investigated. The microstructure of hydrated composites was also examined with a scanning electron microscope.

Keywords: waste glass, glass cullet, glass powder, cement mortar, physical interaction

Streszczenie

W niniejszym artykule opisano wpływ szkła odpadowego na właściwości zaprawy cementowej. Do badań zastosowano barwione szkło odpadowe w dwóch formach: stłuczki szklanej o uziarnieniu 0,125-4 mm wykorzystywanej jako kruszywo drobne i mączki szklanej o uziarnieniu poniżej 0,125 mm wykorzystywanej jako zamiennik cementu. Oba rodzaje szkła uzyskano w wyniku kruszenia i mielenia brązowych szklanych butelek jednego pochodzenia. Badania prowadzono na zaprawach, w których piasek w całości został zastąpiony stłuczką szklaną lub cement w 20% został zastąpiony przez mączkę szklaną. W pracy określono wpływ stosowania stłuczki szklanej i mączki szklanej na podstawowe własności technologiczne zaprawy cementowej, tj. na czas wiązania, konsystencję oraz wytrzymałość na ściskanie i zginanie. Ponadto określono czy stosowanie stłuczki szklanej może być przyczyną wystąpienia ekspansji na skutek zachodzenia reakcji alkalia-krzemionka. Zbadano też mikrostrukturę próbek pod skaningowym mikroskopem elektronowym.

Słowa kluczowe: szkło odpadowe, stłuczka szklana, mączka szklana, zaprawa cementowa, oddziaływanie fizyczne

1. INTRODUCTION

Concrete is one of the most widely used construction materials in the world. Many scientific papers have been written on the research of the technology of its production. A number of them focus on the possibility of utilising various waste materials from other industrial sectors for the production of both concrete, as well as the binder itself. The use of such materials could affect the properties of concrete in different ways. Granulated blast-furnace slag, which for many years was considered to be a waste product and was stockpiled in heaps, is now a desirable material for the production of cement [1]. Binders containing granulated blast-furnace slag, as well as other mineral

*Kielce University of Technology, Poland, e-mail: p.czapik@tu.kielce.pl

additives which, according to standard PN-EN 206 [2] are classified in the II group, may improve the properties of concrete and affect its strength and durability. Other waste materials do not have such favourable properties but may act as type I additives in concrete and can be utilised as fillers. However, when using such materials it is necessary to avoid adding any components to concrete that could be detrimental and reduce its durability. It would be especially harmful if concrete contained any internal corrosion-promoting components [1, 3]. This type of degradation can be even more dangerous than degradation generated by environmental factors because it can be present across the whole volume of the concrete, rather than gradually advancing from its surface. Factors which can potentially be found in waste materials, and which could reduce the durability of cement composites are sulphates, chlorides and reactive silica. Waste glass is one of the waste materials that could potentially be entirely made of reactive silica.

Glass is one of the materials that is suitable for recycling and can be relatively easily re-used when melted down. In Europe, glass recycling techniques are among the most advanced, and in some countries up to 85% of glass containers are produced from recycled glass [4]. In Poland, however, only a relatively small percentage of glass is melted down. A large share of glass containers and glass cullet obtained from them are deposited at municipal or illegal dump sites. Therefore, there is a problem of their possible re-use.

In the context of concrete technology, waste glass can be potentially utilised in two ways – as a non-reactive filler, or as a reactive pozzolanic additive. The form in which waste glass is used in the production of concrete depends mainly on its particle size and its reactivity. It is usually assumed that pozzolanic properties may be demonstrated by glass of a particle size below 0.038-0.3 mm [5, 6], and that in this form it can be used as a cement substitute. Waste glass with a greater particle size can be used as aggregate. In this form, as opposed to glass used as a pozzolanic additive, its high chemical activity is not desirable, as it may cause the degradation of concrete as a result of an alkali-silica reaction. This activity depends on the chemical composition and particle size of glass. Numerous papers [5, 7-12] have been written on the process of the glass pozzolanic and the alkali-silica reaction. The research examined issues such as how the use of different types of glass affects these processes. Previous tests [12] analysed the process of degradation resulting from the alkali-silica reaction in mortars that were made using waste glass obtained through the crushing of selected containers of the same type. It was observed in these tests that during the standard period of testing, glass cullet does not necessarily have to cause a harmful alkali-silica reaction.

The aim of this paper is to analyse the effect of this "harmless", i.e. non-reactive glass, on the main technological properties of mortar, when used both as a finely-ground glass powder, or as fine aggregate instead of the quartz sand fraction, with a 1:1 mass ratio. The use in the tests glass, which will potentially not react with the cement paste components (in pozzolan or alkali-silica reaction), is to prove its physical influence on the mortar properties. This is supplement to numerous research on the glass chemical influence on the mortars.

2. MATERIALS FOR TESTING

During the tests, CEM I 42.5R cement was used as the binder. Sand as per standard CEN PN-EN 196-1 [13] and glass cullet from waste glass were used as the aggregate. Waste glass was also used in the form of glass powder. Glass cullet and powder were obtained as a result of the crushing and milling of brown glass containers of the same origin. Glass was milled using a ball mill with steel balls. After being crushed, waste glass was divided into separate fractions in the course of a screening process. Glass fractions of 0-0.125 mm were classified as powder. The particles of bigger fractions were used to create piles of aggregates with particle sizes required for quartz sand for mortars for the purposes of the specific tests.

Table 1 shows the used cement and glass chemical composition. It demonstrates that the tested glass is soda-lime glass. The density of cement and glass was 3.250 kg/m^3 and 2.495 kg/m^3 respectively.

The tests were carried out on cement paste and mortar samples prepared with a w/c ratio of 0.5. The tests were carried out on samples in which the 100% mass of sand aggregate was replaced with glass

Table 1. Chemical composition of cement and glass [%]

Material	SiO	CaO	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Cl
Cement	19.07	63.99	5.43	1.66	2.79	0.25	0.99	3.41	0.069
Glass	63.89	11.65	4.00	1.25	–	19.21	–	–	–

cullet, or in which 20% mass of the cement binder was replaced with glass powder. Only quartz sand was used as aggregate in mortars with glass powder.

3. TESTING METHODS

In the case of testing binder with a glass powder additive, the effect of the use of this additive on the onset of setting was determined on cement paste samples in accordance with procedures defined in standard PN-EN 196-3 [14], as was its effect on phase changes. Cement paste served as a reference sample. Phase changes present in the period of 28 days were tested via x-ray diffraction, using an Empyrean (PANalytical) diffractometer. The pastes for these tests were kept in plastic bags, wherein after 24 hours distilled water was added to these bags to ensure adequate curing conditions.

The consistency of mortar containing standard aggregate or glass cullet was determined using the flow table test in accordance with the PN-EN 1015-3 standard [15], as well as compressive and flexural strength in accordance with the PN-EN 196-1 standard [13] after 2, 7 and 28 days. The particle size of glass cullet used for the production of this mortar was the same as the particle size of standard sand according to CEN PN-EN 196-1 [13]. Standard cement mortar containing quartz sand was used as reference mortar.

The microstructure of fractured 28-day mortar samples was also tested using a Quanta FEG 250 (FEI) electron scanning microscope equipped with an EDS (EDAX) X-ray microanalyser. Analyses were carried out in low-vacuum conditions (30 Pa), on unsprayed samples, using a 5 kV electron beam.

Additionally, the results of alkaline reactivity tests on glass cullet, carried out using the accelerated method as per ASTM C 1260 [16], were demonstrated.

4. PRESENTATION OF TEST RESULTS

4.1. Results of tests of cement paste with glass powder

Table 2 shows the results of the testing of the initial setting time of a binder in which 20% of cement was replaced with glass powder, in comparison to the results achieved for pure cement binder. It was observed that the tested powder, as well as the use of fly ash [17], extend the period of time which precedes the initial setting time of the binder.

Table 2. Setting time

Binder	Initial Setting Time [min]
CEM I 42.5R cement	415
Cement binder with glass powder	450

Following the bonding of cement with glass powder, tests of the phase changes taking place in this cement during the period of 28 days were tested, as illustrated in Figure 1. It demonstrates diffraction patterns made after 3 and 24 hours and after 28 days of the curing of the cement paste. They primarily reveal peaks generated by clinker phases and by products obtained as a result of their hydration, mainly portlandite. The analyses of the reference paste and the paste containing glass powder, which were carried out at different dates, demonstrate differences in the intensity of various phase peaks. The background also rises with time, indicating the formation of an amorphous C-S-H phase. In the case of glass-containing paste, lower reflections from portlandite can be observed. However, this is not necessarily the result of its participation in the pozzolanic reaction [1, 17, 18]. It is related to the lower content of cement in this sample. This is evidenced by the lower intensity alite peaks, the hydration of which is the main source of portlandite present in the cement paste [1]. The increase of the portlandite peaks in the cement paste and in the glass powder-containing paste, combined with the reduction of clinker phases and gypsum peaks, can be observed mainly during the first 24 hours. No reduction of portlandite reflections indicating the pozzolanic properties of glass powder, was observed after this period.

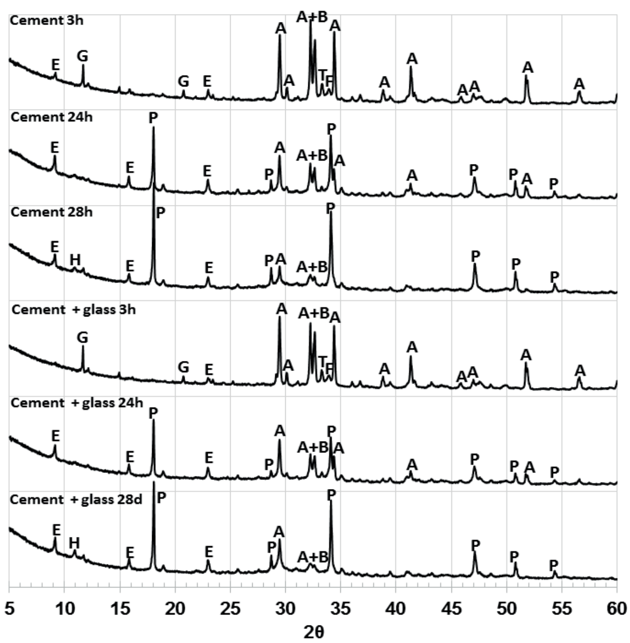

Fig. 1. Diffraction pattern of pastes made using cement binder and a mixture of 80% cement and 20% glass powder recorded after 3 and 24 hours and 28 days of hydration: A – alite, A+B – area of reflections common for alite and belite, E – ettringite, F – brownmillerite, G – gypsum, H – C-S-H, P – portlandite, T – C3A

Table 3. Properties of mortars with waste glass

Mortar	Consistency [mm]	Flexural strength after No. of days [MPa]			Compressive strength after No. of days [MPa]		
		2	7	28	2	7	28
CEM I 42.5R cement	144	6.1	7.3	8.3	30.9	43.9	51.2
Cement mortar with glass powder	158	4.9	6.0	7.0	24.9	34.3	40.6
Cement mortar with glass cullet	108	4.5	4.9	5.1	22.3	32.3	34.7

4.2. Results of the testing of mortars with waste glass

Table 3 shows a list of results of the comparison of the effect of waste glass in the form of powder and cullet on cement mortar technological properties.

Figure 2 illustrates the comparison of mortar consistency measured using the flow table test. It demonstrates that waste glass in the form of powder, used instead of cement and in the form of cullet instead of sand, has a different effect on mortar flowability. The use of glass cullet caused a significant reduction in flowability and only a limited flow was achieved. This may indicate a higher water demand of glass cullet than in the case of standard sand. It was also observed that the replacement of cement with glass powder caused higher flowability. The introduced glass, unlike cement, does not react with water in hydration processes, so it does not reduce the liquid phase content in the system. This and the larger glass powder grains size contribute to its lower water demand compared to cement. The increase flowability could be also a result of the increase in the volumetric content of fine fractions in the mortar. This is due to the different density of cement and glass which replaces it. A reverse effect was achieved when replacing sand with glass cullet. In this case, the replacement of sand with lighter glass results in a higher volumetric content of aggregate in the mortar, and therefore the reduction of the content of dusty/ultra-fine fractions, which is unfavourable in the context of workability [18]. Changes in the volume of binder and aggregate resulting from the use of waste glass are very low and amount to less than 1%.

Figures 3 and 4 illustrate the effect of waste glass on the values of the flexural strength and compressive strength of mortar in a period of 28 days. The use of glass powder, as well as glass cullet, resulted in lower strength values in comparison to the reference sample. In the case of the use of glass powder instead of cement, strength values were always lower by approximately 20%, which corresponds to the percentage of cement that was replaced by finely-milled waste glass. Thus, the pozzolanic properties of the tested glass powder could not be confirmed.

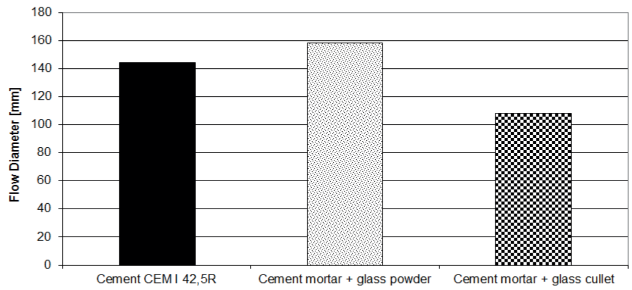

Fig. 2. Consistency of mortars

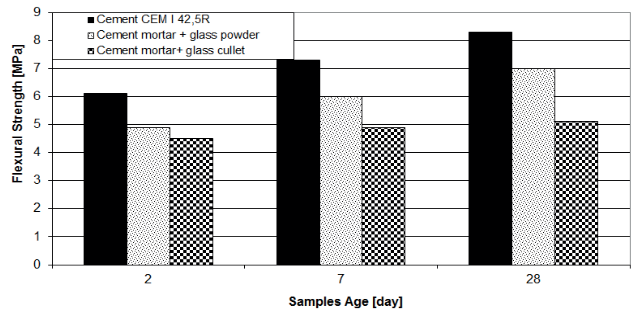

Fig. 3. Flexural strength

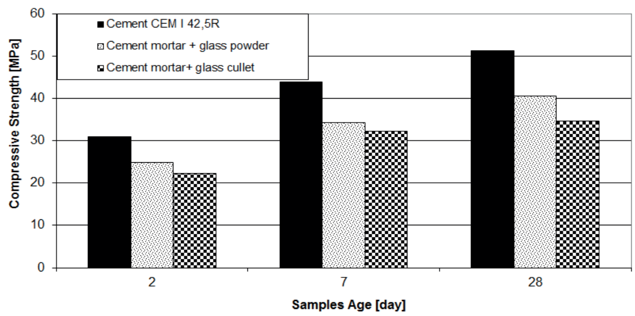

Fig. 4. Compressive strength

Higher reduction of strength values was observed when using glass cullet as aggregate, amounting to approximately 30%. However, the percentage reduction of strength in comparison to the reference mortar is constant over time, as is the case with glass powder-containing samples. It can therefore be concluded that it is not caused by chemical processes. It may be caused by the properties of glass itself, as well as by the properties of the resulting paste-aggregate interfacial transition zone. In order to verify this, testing of the microstructure of the prepared mortars was subsequently carried out.

Figures 5, 6 and 7 illustrate the microstructure of mortar with glass powder and cullet. In the case of the microstructure of mortar with glass powder (Fig. 5), fine glass particles are visible as embedded in the C-S-H phase. The resultant C-S-H phase has obtained a fibrous or "honeycomb" form (Fig. 6), which is characteristic of the setting process of cement without mineral additives [1]. No amorphous, compact microstructure, which was visible during the hydration of cement in the presence of glass powder with pozzolanic properties, was observed [1, 11]. An analysis of the elemental composition of the C-S-H phase revealed significant indications of silicon, which can be attributed to the presence of glass particles dispersed in the cement paste matrix.

Figure 7a illustrates the microstructure of mortar with glass cullet. Many of the glass particles have an elongated, flat shape. This differentiates glass cullet from sand, which normally has more regular particles. The glass powder particles visible in Figure 5 also have the form of a thin plate. This would suggest that glass particles have a larger specific surface area than sand particles. This, together with the difference between the density of glass and sand, is another reason which would explain the lower liquidity of mortar with glass cullet, because a larger specific surface area causes higher water demand [18, 20]. Air voids can also form more easily between irregular aggregate particles, and more cement paste is needed to fill them, which can result in lower strength parameters of the mortar.

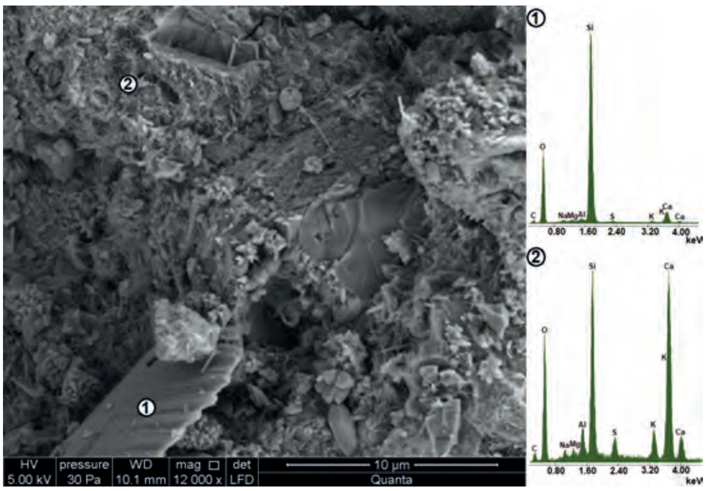

Fig. 5. *Microstructure of the fracture of mortar with glass powder and EDS analyses in points 1 and 2*

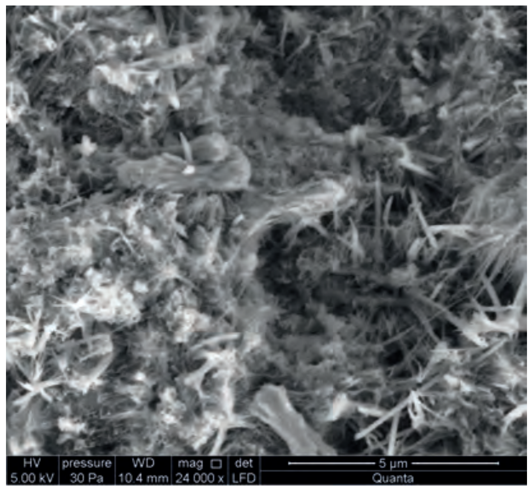

Fig. 6. *C-S-H phase with ettringite in the matrix of cement paste with glass powder*

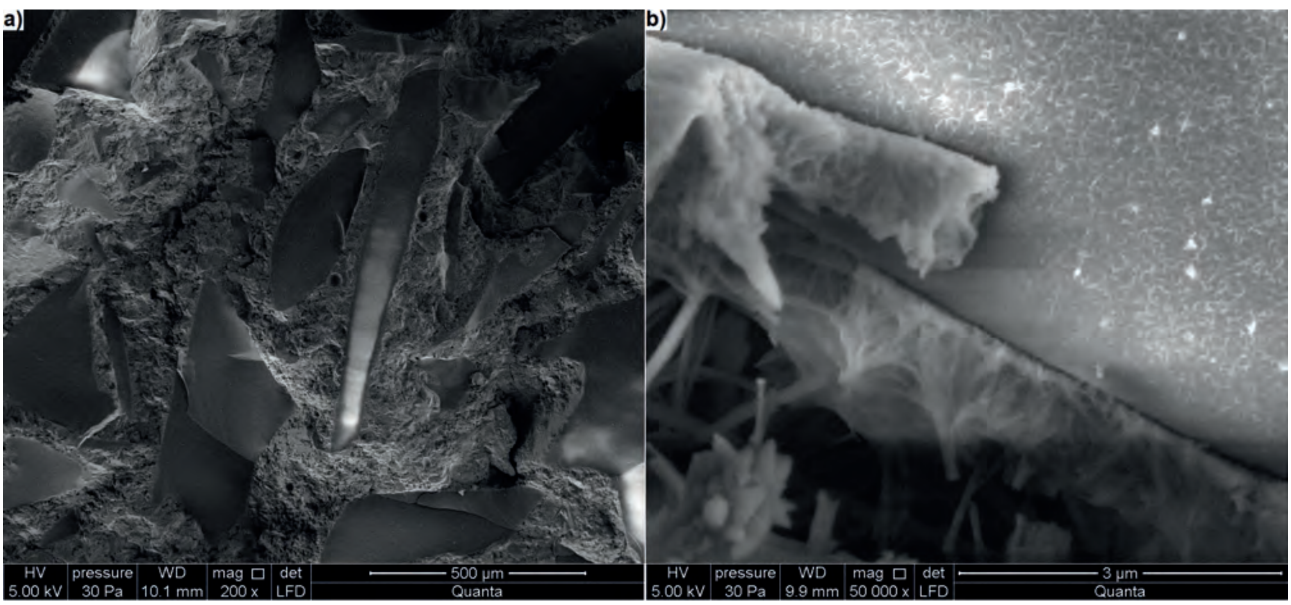

Fig. 7. *Microstructure of mortar with glass cullet*

It was also observed that no cracks or large pores can be seen between the glass and the cement paste, which demonstrates good bonding between the paste and aggregate (Fig. 7a and 7b). Only the accumulation of characteristic, plate-like portlandite crystals can be observed in this zone in some places. The glass particles themselves do not demonstrate any signs of major fracturing either. Their surfaces were usually smooth, but some were covered by products resembling C-S-H phase seeds, resulting from the pozzolanic reaction (Fig. 7b). These could be the products of an early phase of the alkali-silica reaction [3].

The non-reactivity of the tested waste glass is evidenced by the results of the testing of the mortar expansion in a 1M NaOH solution at 80°C, carried out in accordance with standard ASTM C 1260 (Fig. 8).

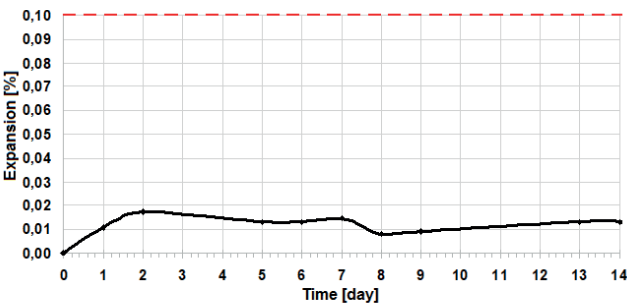

Fig. 8. Expansion of mortar with glass cullet acc. to ASTM C 1260 [16]

The achieved expansion did not exceed the threshold of 0.1%, which would suggest that a potentially deleterious alkali-silica reaction is taking place. These results are consistent with the results of the same tests carried out for brown glass by Najduchowska et al. [10]. Different results were, however, achieved for such glass by Jin et al. [21] and by Park and Lee [22]. In their paper, Park and Lee [22] demonstrated that brown glass is more susceptible to alkali-silica reactions and may exceed the 0.2% expansion threshold after 6 days of testing. Additionally, in a previous paper [12] it was established that the tested glass may cause significant mortar expansion in the case of long-term storage in an NaOH solution. Therefore, the non-reactivity of the tested glass applies only to tests performed during a standard-defined period, which should ensure that in real-life conditions a structure made of the tested material is suitably functional. But in conditions of extreme exposure to harmful factors, the tested glass could demonstrate reactivity. The effects of this can be clearly seen in a microscopic image of a 6-month-old mortar section (Fig. 9), which was initially used for testing in acc. with ASTM C 1260 [16] and was subsequently kept in water [12]. Extensive fracturing of the glass particles and single cracks running across the paste can be seen.

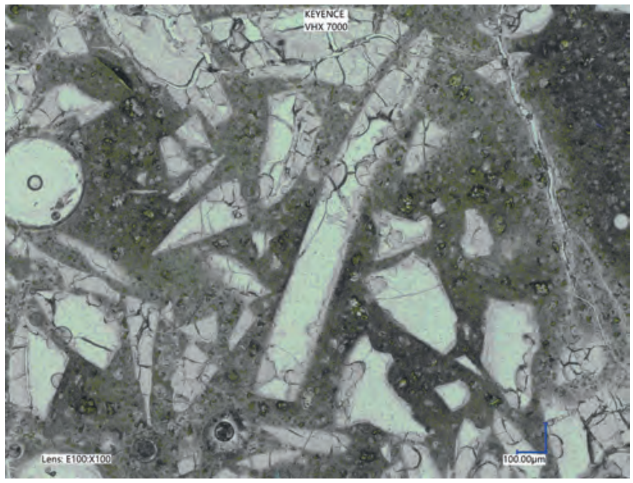

Fig. 9. Cracks in 6-month-old mortar

5. SUMMARY

During the conducted tests, the tested glass did not demonstrate any significant chemical activity. The tested brown packaging glass was not found to enter into a pozzolanic reaction or an alkali-silica reaction. Thus, the effect of glass on the properties of the tested cement composite was of a physical character.

It was found that the use of waste glass, both as a binder substitute and as an aggregate substitute, resulted in the reduction of the strength parameters of mortar. In the case of the replacement of cement with glass powder, this is related to the reduction of the binder content and is proportional to this reduction. In the case of the use of glass cullet, this reduction of parameters is related to the shape of their particles and differences in volumetric content resulting from the relatively low density of glass. It could also be caused by the mechanical properties of glass. Differences in volumetric content may also be responsible for the different effect of the use of glass powder and cullet on the consistency of mortar.

In view of previous testing, it must also be noted that non-reactive glass used during testing may actually demonstrate chemical activity in extreme conditions [12] or in the event of the presence of an activator in the mixture. Thus, the effect of different activating factors on its chemical properties can be tested during further research on the possibility of using non-reactive glass. Factors which may affect reactivity include particle size, and glass powder used for the tests (fraction 0-0.125 mm) was of a maximum particle size that, according to some sources [5], prevents the achievement of pozzolanic activity. Comparative tests of other types of glass should be performed because it is known that even packaging glass of a different colour can demonstrate different properties [10, 21-23].

REFERENCES

[1] W. Kurdowski: *Cement and concrete chemistry, Polish Cement Association*, Kraków 2010, ISBN 978-83-91315-24-8.
[2] PN-EN 206+A1:2016-12 Concrete – Part 1: Specification, performance, production and conformity,
[3] Z. Owsiak: *Internal corrosion of concrete*, Wydawnictwo Politechniki Świętokrzyskiej, Kielce 2015, ISSN 1897-2691.
[4] A. Kuśnierz: *Glass recycling*, Prace Instytutu Ceramiki i Materiałów Budowlanych 2010, 3, 22-33, ISSN 1899-3230.
[5] Y. Shao, T. Lefort, S. Moras, D. Rodriguez: *Studies on concrete containing ground waste glass*, Cement and Concrete Research 2000, 30, 91–100, ISSN 2666-5492.
[6] A.M. Matos, J. Sousa-Coutinho: *Durability of mortar using waste glass powder as cement replacement*, Construction and Building Materials 2012, 36, 205–215, ISSN 0950-0618.
[7] A. Shayan, A. Xu: *Value-added utilisation of waste glass in concrete*, Cement and Concrete Research 2004, 34, 81-89, ISSN 2666-5492.
[8] R. Idir, M. Cyr, A. Tagnit-Hamou: *Pozzolanic properties of fine and coarse color-mixed glass cullet*, Cement and Concrete Composites 2011, 33, 19-29, ISSN 0958-9465.
[9] R. Idir, M. Cyr, A. Tagnit-Hamou: *Use of fine glass as ASR inhibitor in glass aggregate mortars*, Construction and Building Materials 2010, 24, 1309-1312.
[10] M. Najduchowska, E. Pabiś, G. Rolka, T. Baran: *Properties of concrete containing waste glass*, [in:] Monografie Betonu, Polish Cement Association, Kraków 2018, ISBN 978-83-61331-28-5.
[11] J. Deja, E. Gołek, Ł. Kołodziej, A. Różycka: *The properties of pastes based on portland cement with the domestic glass addition*, Procedia of the VI Dni Betonu Conference, Polish Cement Association, Kraków 2010.
[12] P. Czapik: *Microstructure and Degradation of Mortar Containing Waste Glass Aggregate as Evaluated by Various Microscopic Techniques*, Materials 2020, 13, 2186, EISSN 1996-1944.
[13] PN-EN 196-1:2016-07 Methods of testing cement – Part 1: Determination of strength.
[14] PN-EN 196-3:2016-12 Methods of testing cement – Part 3: Determination of setting times and soudness.
[15] PN-EN 1015-3:200 Methods of test for mortar for masonry – Part 3: Determination of consistence of fresh mortar (by flow table).
[16] ASTM C1260 – 14 Standard Test Method for Potential Reactivity of Aggregates (Mortar-Bar Method).
[17] Z. Giergiczny, M. Gawlicki: *Fly ash as active cements component and mineral admixture to concrete*, Procedia of the III Dni Betonu Conference, Polish Cement Association, Kraków 2004.
[18] A. M. Neville, *Properties of Concrete, 5th ed., Polish Cement Association*, Kraków 2012, ISBN 978-83-61331-16-2.
[19] P. Czapik, M. Wolniewicz: *Microsttructure of cement paste containing large amount of silica fume*, [in:] Monografie Betonu, Polish Cement Association, Kraków 2018, ISBN 978-83-61331-28-5.
[20] T. Gawenda: *Innovative technologies of the regular particle aggregate production*, Mining Science – Mineral Aggregates 2015, 22, 45-59, ISSN 2300-9586.
[21] W. Jin, C. Meyer, S. Baxter, *"Glascrete" – concrete with glass aggregate*, ACI Materials Journal 2000, 97, 208-213, ISSN 0889-325X.
[22] S.-B. Park, B.-C. Lee: *Studies on expansion properties in mortar containing waste glass and fibers*, Cement and Concrete Research 2004, 34, 1145–1152, ISSN 2666-5492.
[23] K. Borek, P. Czapik, R. Dachowski: *Recycled glass as a substitute for quartz sand in silicate products*, Materials 2020, 13, 1030, EISSN 1996-1944.

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REQUIREMENT OF PRESSURE RELIEF DAMPERS FOR CLEAN ROOMS

POTRZEBA STOSOWANIA KLAP NADCIŚNIENIOWYCH DO POMIESZCZEŃ CZYSTYCH

Bronislava Hrnková*, Dávid Hečko, Andrej Kapjor, Pavol Mičko, Martin Vantúch
University of Žilina, Slovakia

Abstract

The clean room is designed and used to minimize the entry, generation and deposition of pollutants. Proper flow control is an important factor in determining the efficiency of clean rooms. It is important that the air stream entrains from the space all the particles that are released when people move, but also from equipment and various materials. Therefore, in the following article we will deal with the need for pressure dampers in clean rooms.

Keywords: clean room, pressure dampers, supply air, pressure drop, air diffusers

Streszczenie

Pomieszczenie czyste jest zaprojektowane i wykorzystywane w taki sposób, aby zminimalizować wnikanie, generowanie i osadzanie się zanieczyszczeń. Właściwa kontrola przepływu powietrza jest istotnym czynnikiem określającym efektywność pomieszczeń czystych. Ważne jest, żeby strumień powietrza porywał z przestrzeni wszystkie cząstki, które są uwalniane podczas ruchu ludzi, ale także ze sprzętu i różnych materiałów. W związku z powyższym w niniejszym artykule zajmiemy się potrzebą stosowania klap nadciśnieniowych w pomieszczeniach czystych.

Słowa kluczowe: pomieszczenie czyste, klapy nadciśnieniowe, dopływ powietrza, spadek ciśnienia, dyfuzory

1. INTRODUCTION

Clean rooms are special enclosed spaces, designed as a prefabricated installation into an existing building. A dust-free environment will serve as the basis for a clean room with high hygienic requirements. Such a clean space is formed by elements that ensure hermetic isolation from the external environment. In order to meet the purity class, the concentration of particles in the room must be sufficiently regulated. The cleanliness and regulation of these environments is ensured by powerful air-conditioning devices with high-quality filtration at the inlet (air intake) and also at the outlet (clean air outlet to the room). The design of clean rooms allows you to control the air quality inside the rooms. The main parameters monitored in a clean room are purity class, number of particles in the air, type of flow – laminar/turbulent, temperature and humidity, pressure, sterility, technology and lighting.

The air conditioning system is the most complex and the most demanding part of a clean room to operate. The basic role of air conditioning in a clean room is to protect not only people inside the room, but

*University of Žilina, Slovakia, e-mail: bronka.pucekova@gmail.com

also products and the environment. Due to the basic role of air conditioning in clean rooms, ie the supply of a sufficient amount of air with defined parameters and especially the emphasis on its cleanliness, air conditioning in clean rooms is provided with three-stage filtration. The final element of filtration are HEPA filters. The parameters of HEPA filters are given primarily by the requirement for environmental cleanliness and air flow. Another and no less important parameter is the pressure drop [1].

One of the most important factors that determine the efficiency of clean rooms is proper flow control. It is important that the air stream entrains from the space all the particles that are released when people move, but also from equipment and various materials. Thus, the air stream must bypass all surfaces in the clean room and remove the particles from these surfaces [2].

2. MEASUREMENT METHODS

The type, number and location of air supply diffusers, as well as the exhaust grilles, are an important factor in a turbulently ventilated clean room. Air to a clean room can be supplied with or without a diffuser. Air diffusers are used in many air-conditioned rooms and are located where the supply air enters the room; they are designed to minimize drafts caused by high air velocities and ensure good air mixing. This is shown in Figure 1.

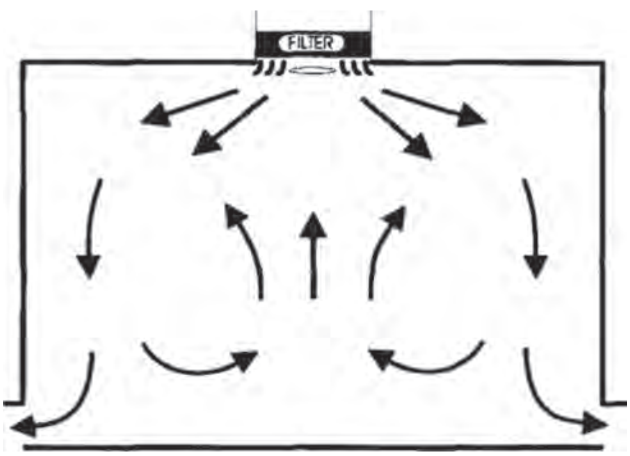

Fig. 1. Airflow conditions produced by a ceiling diffuser (Whyte, 2001)

In some normally ventilated clean rooms, diffusers are not used and the supply air is "discharged" directly from the air filter into the clean room. This method is chosen to obtain a unidirectional flow and good conditions for controlling contamination under the filter; this is schematically shown in Figure 2.

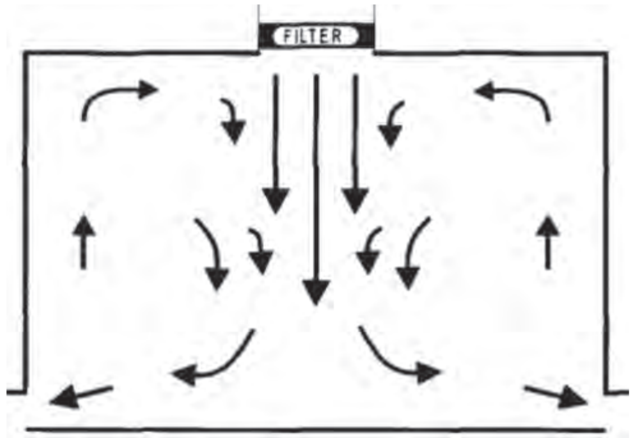

Fig. 2. Aifflow conditions produced by a "dump" system (Whyte, 2001)

In areas of higher cleanliness, the air pressure must be higher than in less clean areas (overpressure ventilation). This is to prevent pollution from entering a cleaner environment into a cleaner space. It is also undesirable for the penetration of pollution from the external environment. Exceptions are clean rooms where hazardous substances are handled. In these clean work areas, the air pressure must be lower than in the surrounding environment (vacuum ventilation) [2].

Areas in which persons reside for a long or short time must be ventilated. This is achieved by either natural ventilation or machine forced ventilation. Ventilation depends on the number of people, their activity, heat balance and the amount of polluted air. The requirements for the minimum amount of air required for breathing, the cleanliness of the indoor air and the removal of degraded air by various odors must be met. Natural ventilation, intended for air exchange, can be used especially in areas without a source of excessive heat and pollutants. These are spaces where one to two changes in the intensity of untreated air is sufficient. In other cases, where natural ventilation is not sufficient, forced ventilation is used. The number of openings, the location of the air supply and exhaust ducts and the type of ventilation shall be determined by expert calculation [3].

3. RESULTS OF THE CLEAN ROOM

In Figure 3, the air will leave the central production room to the clothes change and material transfer areas and further to the outdoor corridor. To ensure that the movement is in the right direction, the air flow can be observed with smoke, water vapor or a stream of air. Although this method is satisfactory in creating a clean room before handover, it is not a possibility

environment

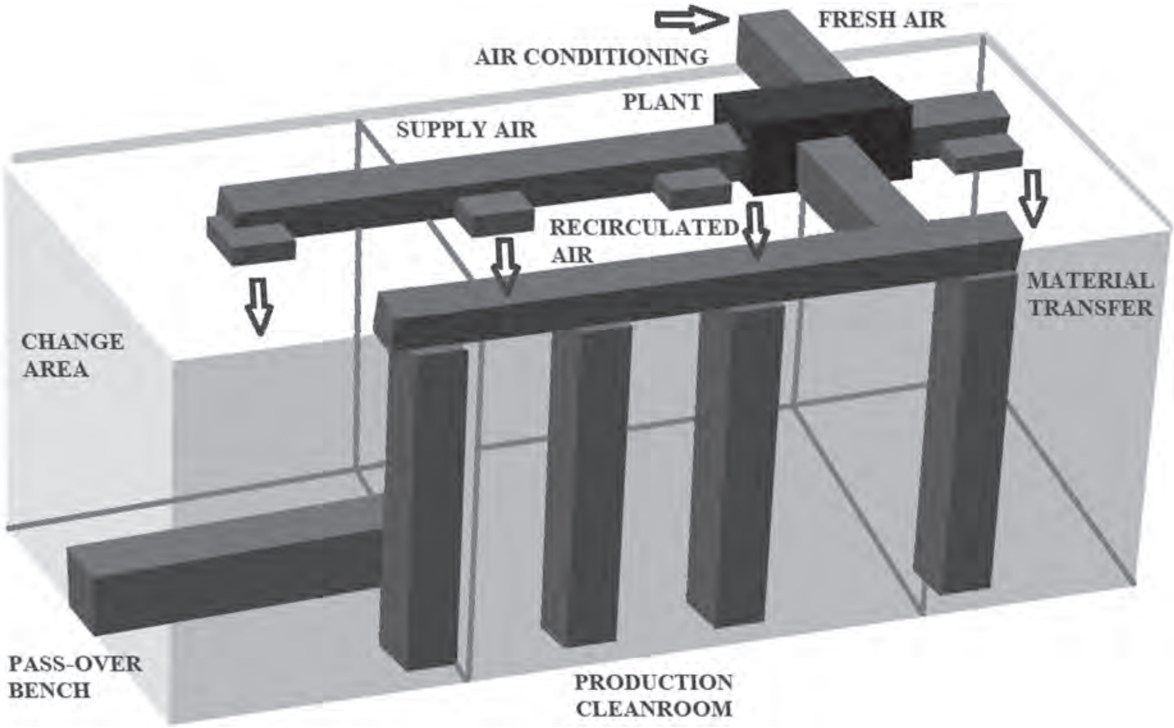

Fig. 3. A turbulently ventilated cleanroom (own source)

of long-term monitoring. To monitor a clean room, it is common practice to check that cleaner areas are under positive pressure than less clean neighboring areas. If the pressure in a clean room is higher than in the adjacent area, air will flow from the clean room to the adjacent area. Differential pressures of 10 Pa between two clean rooms and 15 Pa between a clean room and an unclassified area are appropriate design pressures (12 Pa, 0.05 inch water meter). Where practical difficulties arise in achieving these pressures, e.g. where there is a supply tunnel connecting the two areas, a minimum pressure difference of 5 Pa may be acceptable. In a clean room suite, the air pressure should be adjusted so that the air moves from clean to less clean areas. This means that the highest pressure should be in the production area [3].

Figure 4 is a diagram of a set of clean rooms, which is slightly more complicated than Figure 3, because it has two rooms in the area of changing clothes, and therefore it is necessary to maintain another pressure difference. In this suite, the production room would be set to a pressure of 35 Pa compared to the external access corridor. This is necessary to achieve a pressure difference of 10 Pa between the production room and the changing room, a difference of 10 Pa between the changing room and the changing room and 15 Pa between the changing room and the external access corridor; it gives a total of 35 Pa.

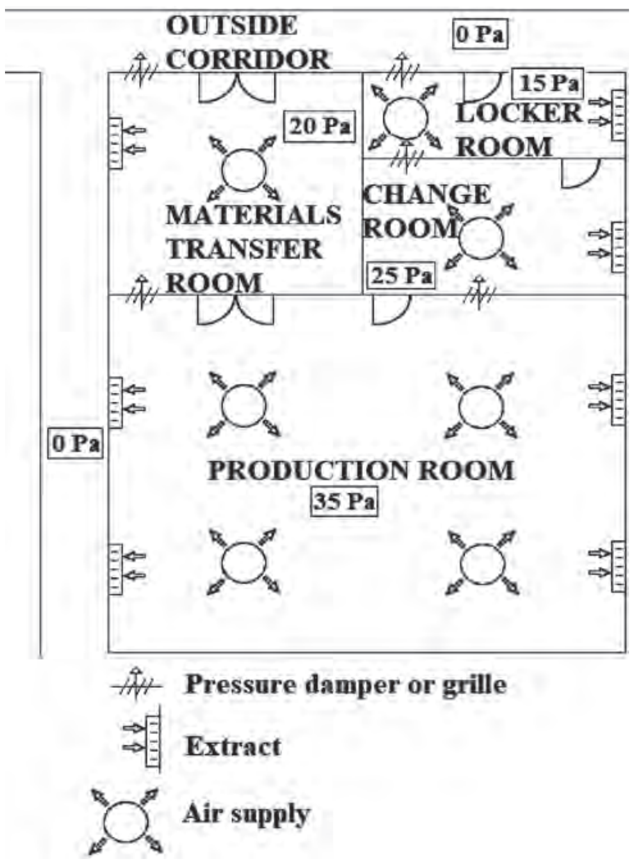

Fig. 4. A simple cleanroom suite showing pressures and aifflow between areas (own source)

environment

Because a pressure difference of 35 Pa is set between the production room and the external corridor, the same pressure is available in the material transfer room.

The material transfer area can therefore be 15 Pa smaller than the production area and 20 Pa larger than the outer corridor; this pressure difference is greater than required but quite acceptable. However, if too large a pressure difference is used, additional energy costs will be incurred. Problems can also occur when trying to open and close a door, as well as "whistling" through cracks [3].

4. CONCLUSION

A clean room must be designed to ensure that contaminated air does not enter the room from dirtier adjacent areas. Therefore, the air should always move from a clean room to less clean adjacent areas. Standards and guidelines set requirements for pressure drop. A pressure drop below 5 Pa is not practical because it cannot prevent air backflow. In addition, such a small pressure difference is difficult to control and is maintained due to the sensitivity of the control elements. Increasing the pressure to more than 20-25 Pa (except for insulator technology) is not rational, because it does not improve the characteristics of the clean room and means a significant increase in costs. There may also be difficulties in opening and closing the door. Due to the high pressure in the air flow, noise can be generated through various types of exhaust grilles or through other air leaks. The pressure drop must be sufficient in size and stability to prevent unforeseen mixing of the air streams.

REFERENCES

[1] Cz. Bestair: *Available on the Internet*, 2021 [cit. 2021-01-14], <https://www.bestair.cz/ciste-prostory/>

[2] D. Tichý: *Design of clean workplace air conditioning for the electrical industry*, Diploma thesis. Technical University Brno, 2008, 76 p.

[3] W. Whyte: *Cleanroom Technology: Fundamentals of Design*, Testing and Operation, Chichester: John Wiley and Sons, 2001, 309 p. ISBN 978-0-471-86842-2.

[4] B. Púčeková: *Laminar field design for clean rooms with variable air supply,* Diploma thesis, Žilina, University od Žilina, 2021, 67 p.

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Bronislava Hrnková, Dávid Hečko, Andrej Kapjor, Pavol Mičko, Martin Vantúch
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ANALYSIS OF THE CONVERSION OF PRIMARY ENERGY INTO HEAT FOCUSED ON A HEAT PUMP WITH A WORKING SUBSTANCE (REFRIGERANT) CO_2

ANALIZA KONWERSJI ENERGII PIERWOTNEJ W CIEPŁO PRZY ZASTOSOWANIU POMPY CIEPŁA Z CO_2 JAKO CZYNNIKIEM ROBOCZYM (CHŁODNICZYM)

Bronislava Hrnková*, Dávid Hečko, Andrej Kapjor, Pavol Mičko, Martin Vantúch
University of Žilina, Slovakia

Abstract

The need for research in the field of energy efficiency and the ecological aspects of primary energy use is currently receiving considerable attention in the framework of European Union policy as well as in the Slovak Republic. It is necessary to deal with this issue not only for the needs of normal operations, but especially in the current situation, when due to the threat of the COVID-19 virus, the requirements for thermal energy are increased. A suitable way to achieve this is the use of renewable resources, in Slovakia mainly biomass, solar, wind, water and geothermal energy. Ambient air, ground heat, heat contained in groundwater and various other waste heat from technological processes represent a huge potential for the use of low-potential energy. The article is focused on solving the problem of conversion of primary energy into heat using thermodynamic cycles and compressor circulation with working substance (refrigerant) CO_2.

Keywords: primary energy, heat pump, CO_2 refrigerant, energy efficiency, energy demand

Streszczenie

Potrzeba badań w obszarze efektywności energetycznej i ekologicznych aspektów wykorzystania energii pierwotnej skupia obecnie dużo uwagi w ramach polityki Unii Europejskiej, jak również w Republice Słowackiej. Konieczne jest zajęcie się tym problemem nie tylko dla zapewnienia normalnego funkcjonowania, ale szczególnie w obecnej sytuacji, gdy w związku z zagrożeniem wirusem COVID-19 wzrastają wymagania i zapotrzebowanie na energię cieplną. Odpowiednim sposobem na osiągnięcie tego jest wykorzystanie zasobów odnawialnych, na Słowacji głównie biomasy, energii słonecznej, wiatrowej, wodnej i geotermalnej. Powietrze atmosferyczne, ciepło ziemi, ciepło zawarte w wodach gruntowych i różne inne rodzaje ciepła odpadowego z procesów technologicznych stanowią ogromny potencjał wykorzystania energii niskotemperaturowej. W artykule skupiono się na rozwiązaniu problemu konwersji energii pierwotnej na ciepło za pomocą obiegów termodynamicznych sprężarkowych z czynnikiem roboczym (chłodniczym) CO_2.

Słowa kluczowe: energia pierwotna, pompa ciepła, CO_2, czynnik chłodniczy, efektywność energetyczna, zapotrzebowanie na energię

*University of Žilina, Slovakia, e-mail: bronka.pucekova@gmail.com

1. INTRODUCTION

The use of energy in the built environment is one of the most important aspects that will need to be addressed in the near future. About 40% of primary energy in Europe is in the construction industry. In order to achieve the targets of the Kyoto Protocol, energy use in the built environment must change. So far, most of our air conditioning systems have made a significant contribution to global warming. In order to reduce greenhouse gas emissions, it is necessary to introduce large-scale environmentally friendly heating systems. Eco-labeling of such environmentally friendly systems is one way to encourage and guide customers when choosing products.

One of the most promising technologies for reducing greenhouse gas emissions is electric heat pumps. Heat pumps offer an energy-efficient way of providing space heating and domestic hot water. Although the technical know-how of heat pumping technology is well established, it has not yet gained public recognition worldwide. In Europe, a sustainable market has only been introduced in small countries such as Sweden, Switzerland and parts of Austria. As a result of rising oil and electricity prices combined with rising energy taxes and growing environmental problems, the heat pump market has begun to grow across Europe.

The research by Fang Wanga et al. dealt with energy and exergy analysis of working substances (refrigerants) R744/R32 on a heat pump. This study examined the volume heat capacity, condensing pressure, discharge temperature, compression ratio and performance of the R744/R32 refrigerant mixture and was compared with the parameters of the R22 refrigerant under the same conditions. The authors found that R744/R32 refrigerant mixtures have a positive effect on energy efficiency, volumetric heating capacity and discharge temperature in a heat pump. An interesting finding was also that at a certain concentration of mixtures (15/85 by mass) the heat pump system shows better performance and COP and energy efficiency reach a peak value [1].

The study by M. Pitarch et al. was focused on the theoretical analysis of cycles of air-water heat pumps R744 for heating applications up to 80°C. The present study investigated the performance of different transcritical thermodynamic cycles working with CO_2, from a theoretical point of view by means of the commercial software EES (F-Chart Software). The authors found that the use of heat pumps for the production of sanitary hot water has some differences compared to the use of heat pumps for air conditioning; the final water temperature is quite high (60°C), and the water temperature lift is large (50°C), i.e. the difference between the water temperature inlet and outlet in the hot side is high. These two facts make that the use of CO_2 in transcritical conditions has some technical advantages beyond environmental arguments in comparison to the use of HFCs [2].

The research by V. K. Venkatesh et al. was focused on experimental evaluation of heat pump performance using CO_2 as a refrigerant. The authors chose CO_2 refrigerant as a working substance due to it's properties. The experiment was performed for two different condensers by varying mass flow rate and pressure. The authors evaluated various parameters such as COP (Coefficient of Performance), LMTD (Logarithmic Mean Temperature Difference) and outlet water temperature of condenser. The maximum COP and outlet temperature of water got in the experiments are 4.46 and 48°C and it was got for the condenser-2. The CO_2 refrigerant performance shows better efficiency and reduced environmental impact. So, the CO_2 refrigerant is best replacement for globally used artificial refrigerants [3].

These studies focused on the analysis of R744 refrigerant and the performance of transcritical thermodynamic cycles. However, they did not address the factors of primary energy conversion for different energy carriers and their impact on the environment. Based on the findings of the research, it is important to analyze energy sources in terms of their impact on the environment. This analysis will be the subject of this study.

2. PRINCIPLE OF LOW POTENCIAL HEAT RECOVERY AND TRANSFORMATION

The word heat pump is a collective term for a wide range of products using the same working principle. However, there are many different types of heat pumps that are best suited for different applications. Heat pumps are generally divided into different types depending on the heat source and cooler for which they are intended. All types have their own advantages and disadvantages, as well as the impact on the environment. The most important aspects to consider when evaluating different heat sources are; availability, temperature, annual temperature fluctuations and investment costs associated with the choice of heat source.

Ambient air is by far the most common source of heat for heat pump applications worldwide.

environment

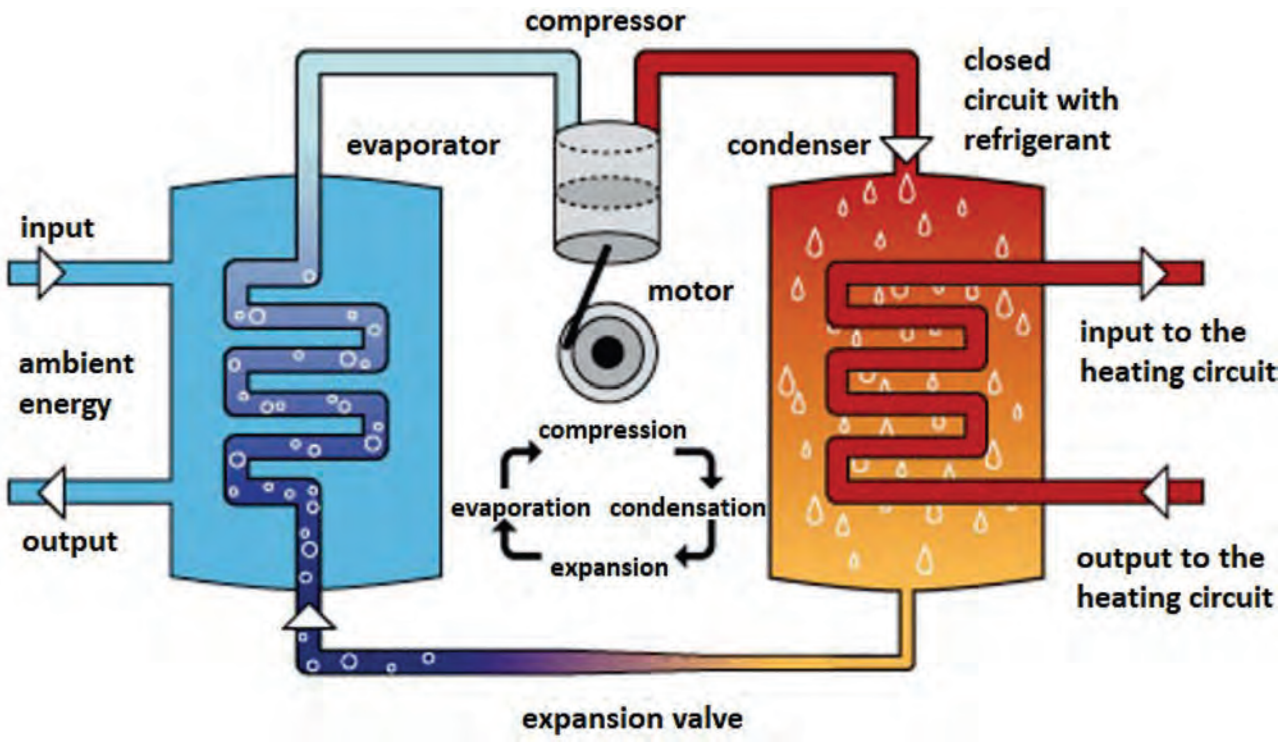

Fig. 1. Air-to-water heat pump principle (own source)

The reason is unlimited availability, which allows uncomplicated and fast installation. In most European climates, the ambient air temperature changes significantly depending on the season. The fact that the output of the heat pump decreases with decreasing temperature of the heat source leads to unfavorable properties. The output of the ambient air heat pump will decrease as the heat demand increases. At some point, the temperature difference between the heat source and the radiator will be large for the heat pump to work at all, and the heat pump must be stopped. For most heat pumps with ambient air, this occurs at temperatures between -15°C and -20°C. In cold climates, this increases the demand for an additional heating system that is designed for the maximum thermal load of the building. Heat pumps are unique in the sense that one and the same appliance is able to provide both heating and cooling. Given that more than 15 000 people died during the 2003 heat wave, cooling space in many parts of Europe is not just a matter of comfort, but a necessity for human well-being. The main number of all heat pumps with air source are designed for dual use, for heating and cooling. Cooling can be achieved by simply reversing the cycle. Small air heat sources sold in the southern part of Europe are mainly used for cooling, while the same unit sold in the northern part of Europe will be used for heating.

The basis of the air-to-water heat pump is a closed circuit filled with refrigerant. The heat pump or cooling circuit has four basic parts:

Evaporator: Low potential heat is supplied to the evaporator by the ambient air. The heat supplied causes the refrigerant to evaporate, the refrigerant vapors become the carrier of thermal energy and are transferred to the compressor. The air flowed through the evaporator by the axial fan or fans is cooled. The air path represents the primary circuit of the heat pump.

Compressor: sucks in steam from the evaporator, compresses it and pushes it into the condenser. The work to drive the compressor is converted into heat, which is added to the heat supplied to the evaporator.

Condenser: the energy supplied to the condenser by the refrigerant vapor from the evaporator and the compressor is transferred to the circulating heating medium (heat pump secondary circuit). The transferred heat heats the heating medium.

Throttle (expansion) valve: liquid refrigerant that has condensed in the condenser at a higher (condensing) pressure is injected into the evaporator to evaporate again at a lower (vaporized) pressure.

environment

The use of soil as a heat source for heat pumps allows the use of renewable energy stored in the soil or subsoil. The earth serves as a seasonal storage of solar energy. At a depth of 0.9-1.5 m, the amplitude of the temperature change due to changes in the outdoor temperature is damped and delayed. The result is very favorable working conditions for a heat pump that obtains energy from the ground. The heat exchanger can be designed for horizontal installation in the ground or vertical installation. Vertical heat exchangers are most often installed in deep boreholes in the built-in subsoil. Installing horizontal loops is generally cheaper than vertical systems. However, vertical systems require a much smaller area. The ground can additionally serve as a cooler for cooling applications or, as in some systems that are designed for "free cooling", provide comfortable cooling with almost no electrical input. Waste air, groundwater and surface water (such as a lake, river or pond) are other examples of commonly used heat sources.

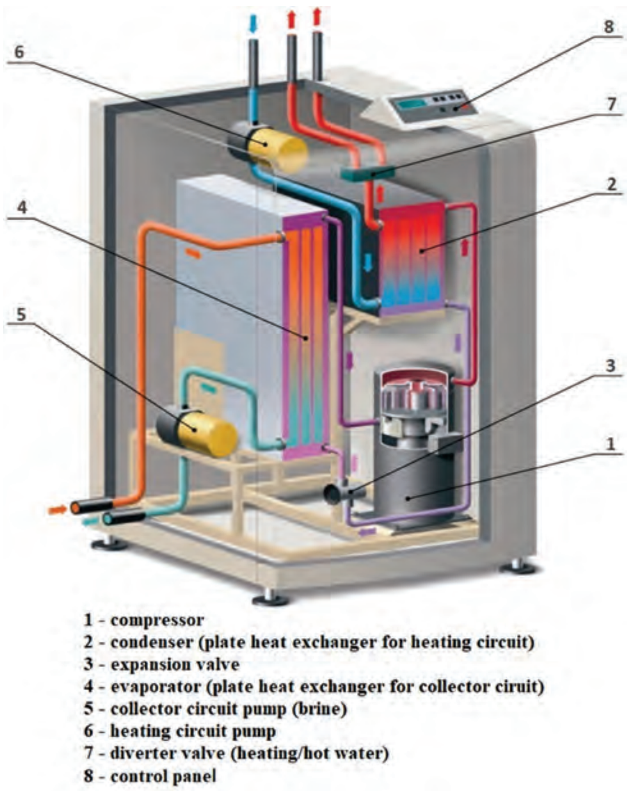

Fig. 2. Ground-water heat pump section (own source)

The overall efficiency of a heat pump system, called the power factor (COP), does not only depend on the efficiency of the system. One and the same appliance will generate completely different annual efficiency factors depending on the temperature levels of the heat source and the heat distribution system. The performance of the unit is tested according to the European standard EN-14511 by accredited testing institutes. The growing interest in this technology has intensified research and development, which has led to significant efficiency gains over the last decade. Compared to a conventional boiler, a highly efficient heat pump system will reduce the use of fossil fuels and reduce hazardous emissions locally. Depending on the production of electricity, emissions occur in operation. However, utility plants generally produce lower emission rates than small domestic furnaces. Indirect emissions from heat pumps both depend on the efficiency of the heat pump system as well as on the efficiency of the electricity generation plant. Emission mitigation is the most significant environmental benefit offered by heat pumps. The range of possible benefits will vary depending on local electricity generation.

3. METHODS FOR ASSESSING THE ENVIRONMENTAL IMPACT OF A HEAT PUMP

However, heat pumps contribute to direct emissions through refrigerant leakage throughout their life cycle. In addition to the leak that occurs during operation, losses will also occur during the demolition of the device. The impact of these losses on the environment will depend on the refrigerant used. The most commonly used refrigerants today are fluorocarbons (HFC). These refrigerants have no ozone depleting potential (ODP), but they contribute to global warming and should therefore be used with caution. Heat pumps have one huge advantage over other types of heating. Heat pump motors (compressors) don't generate all the heat on their own. They only increase the coolant temperature. Most of the heat is taken from the surrounding environment (air, earth, water). The heat pump with natural CO_2 refrigerant (R744) is an ecological alternative to R410A and R32 refrigerants. Fluorocarbon-free climate-friendly technology supports international climate gas commitments. Refrigerant R744 has an ozone depletion potential (ODP) = 0 and a global warming potential (GWP) = 1. CO_2 heat pumps use a compressor that uses R744 refrigerant, which is carbon dioxide (CO_2). Refrigerant R744 (carbon dioxide) used to produce heated and cooling air is a gas that is less harmful to the environment than fluorinated refrigerants.

Environmental assessments of heat pump applications must take into account the indirect

Table 1. Primary energy factors in selected energy carriers (STN EN ISO 52000-1)

Energy carrier	Non-renewable factors PE - $f_{p,nren}$ (Slovak legislation) /STN EN ISO 52000-1	Renewable factors PE - $f_{p,ren}$ (Slovak legislation) /STN EN ISO 52000-1	Factors overall PE - $f_{p,tot}$ /STN EN ISO 52000-1
Natural gas, coal, coke	1.1	0.0	1.1
Wood pellets	0.2	1.0	1.2
Wood chips	0.15	1.0	1.15
Piece wood	0.1	1.0	1.1
Solar, geothermal energy	0	1.0	1.0
Electricity	2.2 / 2.3*	0.2	2.5

* factor $f_{p,nren}$ according to STN EN ISO 52000-1:2017

emissions related to the production of electricity used to operate the heat pump as well as the direct emissions of the refrigerant. Much research has been done on introducing an integrated method for calculating the contribution of greenhouse gas emissions from refrigeration and heat pump applications. The most famous TEWI (Total Equivalent Warming Impact) method was developed at the Oak Ridge National Laboratory in the early 1990s. The TEWI calculation integrates direct and indirect lifetime greenhouse gas emissions into a single number expressed in mass equivalents of CO_2. The TEWI concept is used in the newly developed criteria for the environmental labeling of electrically driven heat pumps within the "Der blaue engel" in Germany [4].

Estimating CO_2 emissions is a basic exercise in assessing environmental behavior. However, there are other measures to compare the performance of the different systems available. The concept of the primary energy ratio (PER) is only the relationship between the useful energy output divided by the required energy input. This value provides a direct value of the overall efficiency of the whole system, taking into account the losses associated with electricity generation. For a conventional combustion plant, the PER value is equal to the total efficiency of the system [1].

4. THE IMPACT OF THE PRIMARY ENERGY NEED ON THE ENERGY CLASS

When analyzing the need for primary energy, it is important to take into account the energy intensity of heat production and transport using the distribution and transformation factor (simply put – the efficiency of converting the energy carrier into heat). So it depends on which heat source we choose – for example, gas condensing has an efficiency of about 105%, a heat pump can have up to 300% (compared to the heat produced consumes only about a third of electricity) [5].

The total energy demand for heating and hot water preparation is divided in the following table based on the Slovak legislation STN EN ISO 52000-1 according to energy carriers (gas, electricity, etc.) and their values are multiplied by the relevant factors. From this, the value of the global indicator, ie primary energy, is obtained. For example, in the case of wood and wood pellets, this factor is close to 0, so that the primary energy requirement is very low. For gas, the primary energy factor is 1.1, for electricity it is 2.2, because its production represents a high environmental burden. Therefore, if you heat with electricity, even with a very low heat demand for heating, you will reach a relatively high value with primary energy [6].

The need for energy for heating and hot water is actually the basis for calculating the cost of operating the house, the primary energy in turn expresses the environmental burden. Although most people look at investing in a heating system mainly through money to run a house and procure technology, the requirement for primary energy must be met by law. If this indicator is not in the required energy class, you will not approve the house. The value of primary energy can be significantly affected by the choice of heat source - even if the total energy demand of the house is in class B, with an ecological heat source (e.g. biomass boiler, heat pump, etc.) the global indicator can get into the right category.

In the case of primary energy, the environmental aspect, i.e. CO_2 emissions, is also taken into account. To put it simply, the energy needed to produce fuel is also taken into account in its calculation. It is essential to classify the house in the energy class according to the value of the global indicator, i.e. primary energy (since January 2021 "A0" energy class is required).

5. CONCLUSIONS

Thanks to the CO_2 refrigerant, the outlet water temperature is adjustable between 60°C and 90°C. While today's best heat pumps can operate at outdoor temperatures of -20°C to -25°C, the R744 models equipped with compressors allow trouble-free operation down to -30°C, at which the heat pump can still reach an outlet temperature of 90°C with a relatively low power drop. Unlike conventional heat pumps, it can be the only source of hot water all year round, so that the produced amount and temperature of water is not reduced at extremely low outdoor temperatures. Carbon dioxide as a heat transfer medium has much better properties than synthetic refrigerants used in pumps. This difference is particularly pronounced in cold climates with a lower outdoor temperature and in hot water supplies with a temperature of around 90°C. CO_2 refrigerant increases energy efficiency compared to traditional pumps, so they can be used even in colder periods and climates. Carbon dioxide heat pumps have a higher energy efficiency than other heat pumps and can also be used in colder climates and periods. CO_2 refrigerant is a natural refrigerant and is the future of refrigeration without HFCS refrigerants.

REFERENCES

[1] F. Wang, X.W. Fan, J. Chev, Z.W. Lian: E*nergy and exergy analysis of heat pump using R744/R32 refrigerant mixture*. Belgrade, 2014, ISSN 0354-9836.
[2] M. Pitarch, E. Navarro-Peris, J. Gonzalvez, J.M. Corberan: *Analysis and optimisation of different two-stage transcritical carbon dioxide cycles for heating applications*. International Journal of Refrigeration, 2016, pp. 235-242.
[3] V.K. Venkatesh, M.G. Basavaraju, K.V. Sreenivas Rao: *Experimental performance evaluation of heat pump by using CO_2 as a refrigerant*. IOP Conference Series: Materials Science and Engineering. 2016, 149 012209.
[4] C. Kutlu, S. Unal, M.T. Erdinc: *Thermodynamic analysis of bi-evaporator ejector refrigeration cycle using R744 as natural refrigerant*, Istanbul, 2016, ISSN 2148-7847.
[5] Decree of the Ministry of Economy of the Slovak Republic No. 308/2016.
[6] STN EN ISO 52000-1: *Energy efficiency of buildings*.

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INFLUENCE OF THE WASTE GLASS USES ON THE CEMENT MORTAR PROPERTIES

WPŁYW STOSOWANIA SZKŁA ODPADOWEGO NA WŁAŚCIWOŚCI ZAPRAWY CEMENTOWEJ

Przemysław Czapik, Dominik Kuza, Michał Boroń
Kielce University of Technology, Poland

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Abstract

In this paper the influence of waste glass on the properties of cement mortar was described. The coloured waste glass in two different forms was used: the glass cullet with a particle size of 0.125-4.00 mm as a fine aggregate and the glass powder with a particle size below 0.125 mm as cement replacement. Both types of glass were obtained by crushing and milling brown glass bottles. The tests were carried out on mortars in which sand was entirely replaced by glass cullet or 20% of cement was replaced by glass powder. The effect of glass cullet and glass powder on the properties of cement mortar, such as setting time, consistency, flexural and compressive strength was determined. Moreover, the role of glass cullet as a potential source of expansion resulted from the alkali-silica reaction was investigated. The microstructure of hydrated composites was also examined with a scanning electron microscope.

Streszczenie

W niniejszym artykule opisano wpływ szkła odpadowego na właściwości zaprawy cementowej. Do badań zastosowano barwione szkło odpadowe w dwóch formach: stłuczki szklanej o uziarnieniu 0,125-4 mm wykorzystywanej jako kruszywo drobne i mączki szklanej o uziarnieniu poniżej 0,125 mm wykorzystywanej jako zamiennik cementu. Oba rodzaje szkła uzyskano w wyniku kruszenia i mielenia brązowych szklanych butelek jednego pochodzenia. Badania prowadzono na zaprawach, w których piasek w całości został zastąpiony stłuczką szklaną lub cement w 20% został zastąpiony przez mączkę szklaną. W pracy określono wpływ stosowania stłuczki szklanej i mączki szklanej na podstawowe własności technologiczne zaprawy cementowej, tj. na czas wiązania, konsystencję oraz wytrzymałość na ściskanie i zginanie. Ponadto określono, czy stosowanie stłuczki szklanej może być przyczyną wystąpienia ekspansji na skutek zachodzenia reakcji alkalia-krzemionka. Zbadano też mikrostrukturę próbek pod skaningowym mikroskopem elektronowym.

REQUIREMENT OF PRESSURE RELIEF DAMPERS FOR CLEAN ROOMS

POTRZEBA STOSOWANIA KLAP NADCIŚNIENIOWYCH DO POMIESZCZEŃ CZYSTYCH

Bronislava Hrnková*, Dávid Hečko, Andrej Kapjor, Pavol Mičko, Martin Vantúch
University of Žilina, Slovakia

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Abstract
The clean room is designed and used to minimize the entry, generation and deposition of pollutants. Proper flow control is an important factor in determining the efficiency of clean rooms. It is important that the air stream entrains from the space all the particles that are released when people move, but also from equipment and various materials. Therefore, in the following article we will deal with the need for pressure dampers in clean rooms.

Streszczenie
Pomieszczenie czyste jest zaprojektowane i wykorzystywane w taki sposób, aby zminimalizować wnikanie, generowanie i osadzanie się zanieczyszczeń. Właściwa kontrola przepływu powietrza jest istotnym czynnikiem określającym efektywność pomieszczeń czystych. Ważne jest, żeby strumień powietrza porywał z przestrzeni wszystkie cząstki, które są uwalniane podczas ruchu ludzi, ale także ze sprzętu i różnych materiałów. W związku z powyższym w niniejszym artykule zajmiemy się potrzebą stosowania klap nadciśnieniowych w pomieszczeniach czystych.

ANALYSIS OF THE CONVERSION OF PRIMARY ENERGY INTO HEAT FOCUSED ON A HEAT PUMP WITH A WORKING SUBSTANCE (REFRIGERANT) CO_2

ANALIZA KONWERSJI ENERGII PIERWOTNEJ W CIEPŁO PRZY ZASTOSOWANIU POMPY CIEPŁA Z CO_2 JAKO CZYNNIKIEM ROBOCZYM (CHŁODNICZYM)

Bronislava Hrnková, Dávid Hečko, Andrej Kapjor, Pavol Mičko, Martin Vantúch
University of Žilina, Slovakia

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Abstract

The need for research in the field of energy efficiency and the ecological aspects of primary energy use is currently receiving considerable attention in the framework of European Union policy as well as in the Slovak Republic. It is necessary to deal with this issue not only for the needs of normal operations, but especially in the current situation, when due to the threat of the COVID-19 virus, the requirements for thermal energy are increased. A suitable way to achieve this is the use of renewable resources, in Slovakia mainly biomass, solar, wind, water and geothermal energy. Ambient air, ground heat, heat contained in groundwater and various other waste heat from technological processes represent a huge potential for the use of low-potential energy. The article is focused on solving the problem of conversion of primary energy into heat using thermodynamic cycles and compressor circulation with working substance (refrigerant) CO_2.

Streszczenie

Potrzeba badań w obszarze efektywności energetycznej i ekologicznych aspektów wykorzystania energii pierwotnej skupia obecnie dużo uwagi w ramach polityki Unii Europejskiej, jak również w Republice Słowackiej. Konieczne jest zajęcie się tym problemem nie tylko dla zapewnienia normalnego funkcjonowania, ale szczególnie w obecnej sytuacji, gdy w związku z zagrożeniem wirusem COVID-19 wzrastają wymagania i zapotrzebowanie na energię cieplną. Odpowiednim sposobem na osiągnięcie tego jest wykorzystanie zasobów odnawialnych, na Słowacji głównie biomasy, energii słonecznej, wiatrowej, wodnej i geotermalnej. Powietrze atmosferyczne, ciepło ziemi, ciepło zawarte w wodach gruntowych i różne inne rodzaje ciepła odpadowego z procesów technologicznych stanowią ogromny potencjał wykorzystania energii niskotemperaturowej. W artykule skupiono się na rozwiązaniu problemu konwersji energii pierwotnej na ciepło za pomocą obiegów termodynamicznych sprężarkowych z czynnikiem roboczym (chłodniczym) CO_2.

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