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Utilization of Luminescent Lamps by a High-pressure Water-jet

Józef Borkowski[*], *Weronika Piestrzyńska-Dziedziejko*[*], *Michał Bielecki*[*], *Przemysław Borkowski*[**]
[*]*Koszalin University of Technology,*
[**]*KGHM Cuprum, Research & Development Centre, Wroclaw*

1. Introduction

As it comes out from the report of Chief Inspector of Environmental Protection [15], over 487 108 Mg of different electric and electronic apparatus had been introduced in. Guidance that describes the rules of classification [21] and evaluation [22] of such equipment usability let to define each of its type. For example, only during 2010 the amount of new lighting equipment that arrived on the market was 4 244 Mg while less than a half of that was removed as impractical one (2 188 Mg) [15].

Significant amount of such removed lighting equipment are environmentally dangerous lamps using luminescent materials [16]. Usually such equipment is produced basing on over 30-ty years old technologies [1, 8, 9]. The most often these are mercury- or luminescent lamps as well as kinescopes. There are specialized technological lines [18, 20] used for utilization of these last one, while fluorescent types of neon lamps are utilized with other special apparatus [17, 19]. Generally all that problems have grown nowadays to the level of global issues because one can find similar solutions in neighbor countries [10, 11]. However one should also have in mind that typical systems for waste material utilization are high-temperature technologies [12–14] and they are not dedicated for such a toxic materials as a non-recycling ones due to the specific character of burning processes.

Considering all technological devices for utilization of luminescent lamps it should be stated here univocally that they have to work hermetically and use vacuum systems for sucking off all the toxic mercury's fumes. In order to limit that problem we have developed alternative method of utilization that uses high-pressure water jet technique. Thanks to absorption of those toxics the water jet causes limitation of aeration zone and ensures increase of applications universalism. Such an effect simultaneously occurs thanks to glass comminution as well as to luminescent materials washing out while the shape of the lamp is practically unimportant. Our previous experience considering utilization of municipal waste with water jet technology [2, 3] was very helpful in resolving discussed here matters.

The aim of this paper is to present research results of luminescent lamps utilization using high-pressure water jet. The paper presents original technological equipment as well as test apparatus and its methodology. One can find here reports of comminuted glass particles' distribution and powders' of washed out luminescent materials as well as results presenting quality aspects of these materials. Technology outline of luminescent lumps utilization is finally presented in too.

2. Research methodic

Developed method of luminescent and kinescope lamps utilization that uses luminophor, needs a special technological line (Fig. 1) to be implemented. They are initially mechanically comminuted first in shredder type machine (3). The next operation is glass comminution in water-jet mill (2), what ensures simultaneously luminophor washing out. All the output goes then into hydro-cyclone (4) where fine-grain glass is separated and cumulated in container (6). Such type water pulp of glass, after drying, periodically is directed to glass-works. The main technological water including toxics, after leaving hydro-cyclone (4), flows through filtering section (5) into the tank (8) which supplies high-pressure pump (1). Luminophor are separated on filtering section (5) and such a humid form is finally collected in a hermetic tank (7). Further process of luminescent materials utilization is realized in a special laboratory (see chapter no. 5).

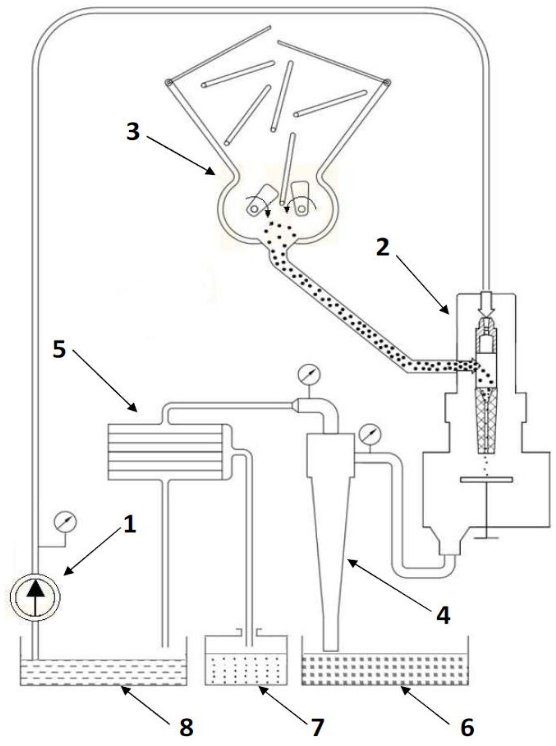


Fig. 1. Test-technological stand scheme:1 – high-pressure water pump, 2 – water-jet mill, 3 – mechanical crusher, 4 – hydro-cyclone, 5 – filter station, 6 – container of glass cullet, 7 – container for the humid luminescent materials, 8 – technological water tank

Rys. 1. Schemat stanowiska badawczo-technologicznego: 1 – wysokociśnieniowa pompa wodna, 2 – młyn hydrostrumieniowy, 3 – kruszarka mechaniczna, 4 – hydrocyklon, 5 –stacja filtrów, 6 – zbiornik na tłuczeń szklany, 7 – pojemnik na wilgotny luminofor, 8 – zbiornik wody technologicznej

The water-jet mill with adequate equipment (Fig. 2) was used for comminution of such a glass chippings that comes from luminescent lamps and this technology was developed and directly adopted from coal micronization [5, 7] process. Glass chippings of the size range 0.5–2 mm were used for further comminution with the process efficiency of the level 0.56–2.65 g/s. The mill was supplied with water at a range of 0.4–1.0 dm^3/s and its pressure was changed 35–50 MPa.

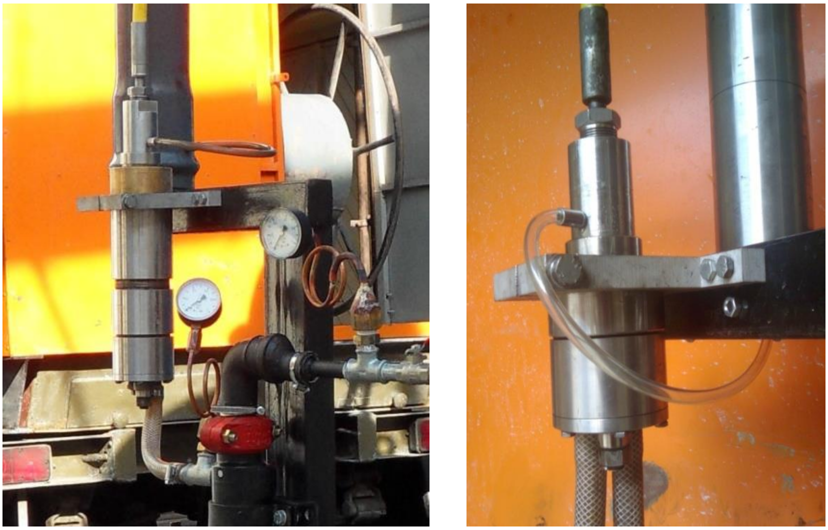


Fig. 2. General and detailed view of water-jet mill
Rys. 2. Widok ogólny i szczegółowy młyna hydrostrumieniowego

Analysette 22 Micro Tec analyzer was used for testing different particles fractions of luminescent material and comminuted glass. It enables fast results evaluation of particles size range of 80 nm up to 2 mm. FEI Quanta 200 microscope equipped with chemical analyzer type EDAX Genesis XM 2i was used to observe luminescent material and glass surface. Additional software was used for particles shape analysis. In turn, topography of cut surface and its geometry was measured with spatial surface analyzer type TalySurf CLI 2000 (Taylor Hobson) using laser gage as well as confocal gauge working with polarized light. Fig. 3 is an example of such research effects that characterizes surface of luminophor being originally sprayed on the internal wall of the fluorescent lamp.

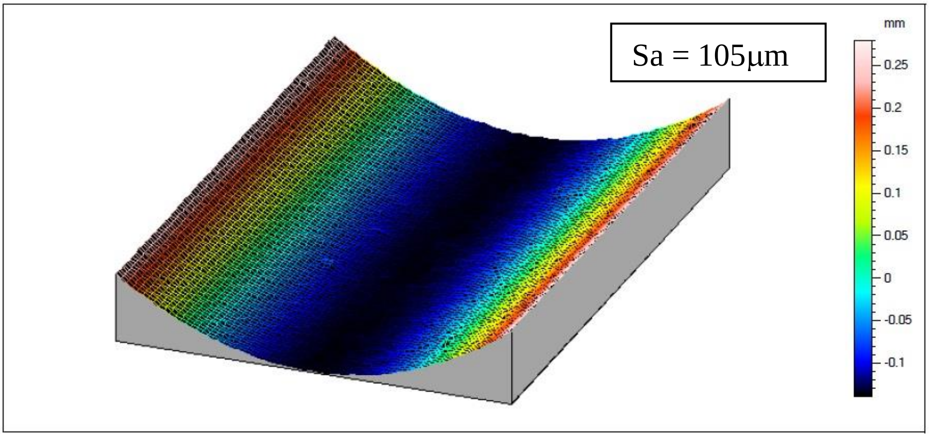


Fig. 3. 3D Talyscan of luminophor being originally sprayed on the internal wall of the fluorescent lamp
Rys. 3. Profilogram 3D powierzchni luminoforu napylonego na wewnętrznej ściance świetlówki

3. Research of particles distribution

Evaluation of high-pressure method of fluorescent lamp utilization needs to carry out the research of comminuted glass particles distribution and the powder of washed out luminescent material.

3.1. Glass particles distribution

The first stage comminution of luminescent lamps being utilized is realized in hermetic mechanical devices. Usually this stage ensures glass comminution to the level presented in Fig. 4 and it helps the main process to be performed with high-pressure water jet causing at the same time the luminophor to be washed out.

As it comes out from previous own work [4, 6], for glass comminution with hydro-jetting technology, one can successively use relatively low water pressure of the level of 40 MPa. Such kind comminution using water-jet mill including the nozzle of diameter of 0.7 mm, ensures process efficiency of Q_c=2.65 g/s, while distribution of glass particles is presented in Fig. 5. Amount of approx. 90% of glass is comminuted after the first stage and becomes range of 0–550 µm.

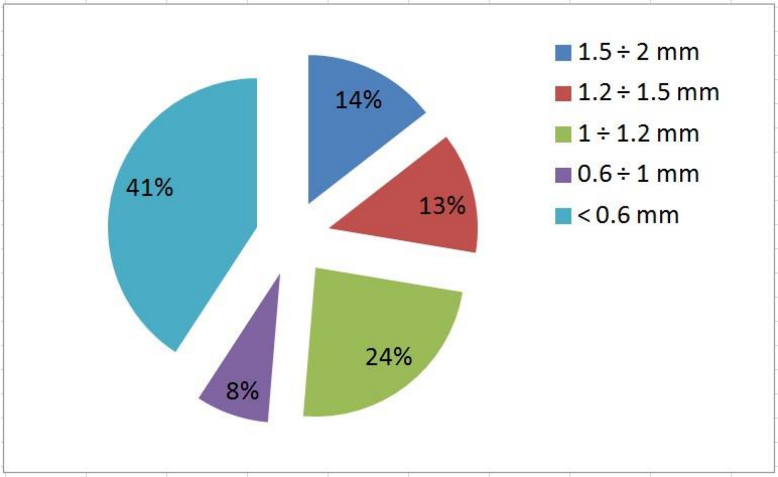


Fig. 4. Percentage composition of glass sample before hydro-jetting comminution
Rys. 4. Procentowy skład nadawy szkła przed rozdrabnianiem hydrostrumieniowym

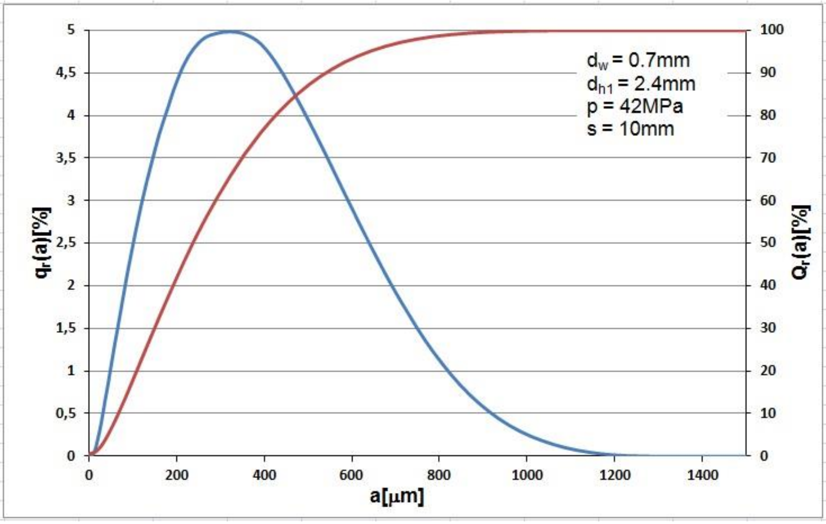


Fig. 5. Distributions of glass particles fractions comminuted with water-jet mill
Rys. 5. Rozkład wielkości cząstek szkła rozdrabnianego w młynie hydrostrumieniowym

Less favorable effects of glass comminution using similar mill but additionally equipped with extension pipe of homogenizing nozzle of 200 mm length, are exemplified in the next Fig. 6. In such conditions, process effectiveness reaches only Q_c=0.56 g/s, while 90% of glass particles are in the range of 0–600 µm.

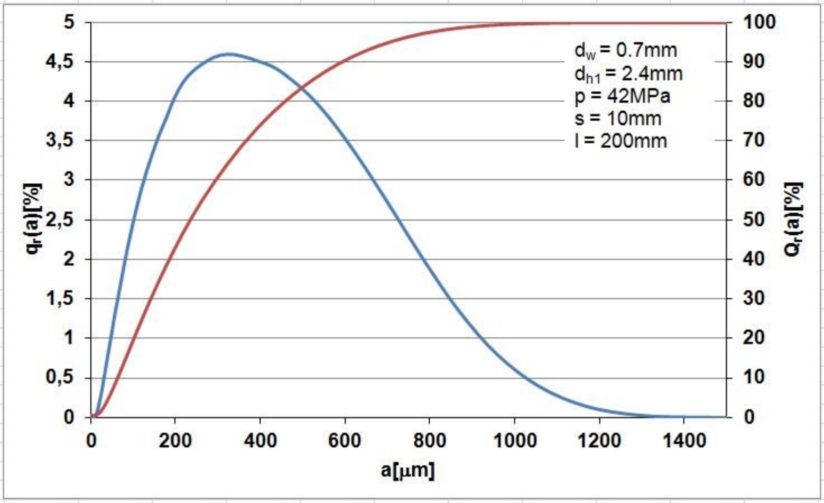


Fig. 6. Distributions of glass particles fractions comminuted with water-jet mill equipped with extension homogenizing nozzle
Rys. 6. Rozkład wielkości cząstek szkła rozdrabnianego w młynie z przedłużoną dyszą homogenizacyjną

Each of these charts was created as a composition of approx. 30 individual charts, which were automatically printed by Analysette 22 Micro Tec apparatus. I comes out from the analysis that comminution in the mill equipped with 0.7 mm nozzle produces usually fractions of 200–400 µm in size. It manifests also in shape diversification of those charts obtained for typical milling as well as for additional pipe extension of homogenizing nozzle.

Better efficiency of such comminution can be achieved for using analogical hydro-jetting mill, but equipped with the largest water nozzle of 1.0 mm in diameter. Comminution in such a mill causes a chance to obtain size fractions of the range 150–300 µm. Exemplary results of such glass particles distribution are presented in Fig. 7 and Fig. 8 (for the mill additionally equipped with homogenizing nozzle extension up to 200 mm).

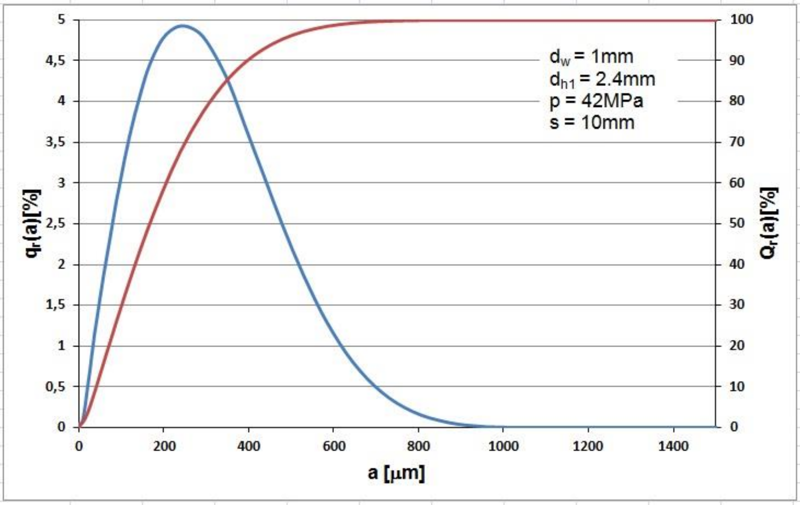


Fig. 7. Distributions of glass particles fractions comminuted with water-jet mill
Rys. 7. Rozkład wielkości cząstek szkła rozdrabnianego w młynie hydrostrumieniowym

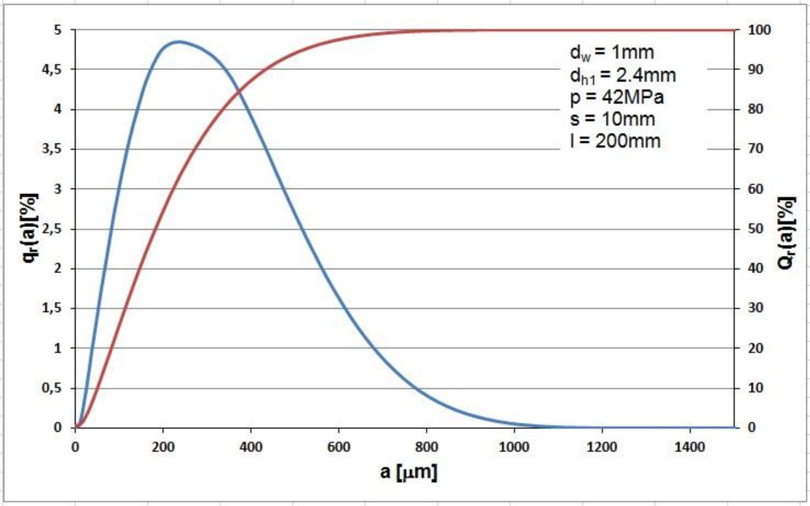


Fig. 8. Distributions of glass particles fractions comminuted with water-jet mill equipped with homogenizing nozzle extension
Rys. 8. Rozkład wielkości cząstek szkła rozdrabnianego w młynie z przedłużoną dyszą homogenizacyjną

Amount of approx. 90% of glass is comminuted after the first stage and becomes range of 0–400 µm for typical homogenizing nozzle that ensures process efficiency of 1.12 g/s (Fig. 7), and respectively reaches 0–450 µm comminution for the nozzle with pipe extension what ensures efficiency of 1.32 g/s (Fig. 8).

3.2. Luminophor particles distribution

As it comes out from the investigation the luminophor particles are practically not comminuted in the water-jetting process. Exemplary effect of such behavior is presented in Fig. 9. Even 50% of luminophor particles washed out during processing gives fraction size range of 0–14.7 µm while size of 90% of these particles does not exceed 36µm.

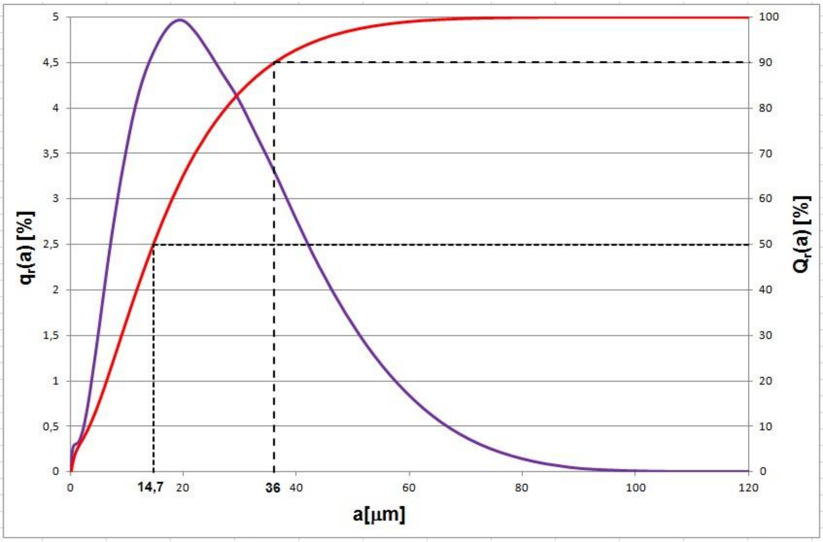


Fig. 9. Distributions of luminophor particles fractions washed out in hydro-jetting mill (d_w=0.7 mm, d_{h1}=2.4 mm, s=10 mm, p=42 MPa)
Rys. 9. Rozkład wielkości cząstek luminoforu wypłukanego w młynie hydrostrumieniowym (d_w=0.7 mm, d_{h1}=2,4 mm, s=10 mm, p=42 MPa)

Size distributions of these particles practically overlap size dimensions of new powder from luminescent lamps.

4. Investigation of comminution materials surface

Evaluation of high-pressure water jet usability for utilization of luminescent lamps needs to investigate the quality of surface of constituent materials, both in the form of comminuted glass particles and washed out powder of luminophor.

4.1. Glass particles surface

After depressurizing luminescent lamps destined to utilization as well as after disassembling of its bases and electrodes, initial crushing process is taking place. It can be realized inside hermetically safe mechanical crushers in order to secure that the luminescent materials stays in place. Glass dimensions obtained in such conditions are presented in Fig. 4 while their outer view can be found in Fig. 10.

a) b)

Fig. 10. Outer view of the glass cullet produced in mechanical comminution. Most particles surface is covered with luminophor

Rys. 10. Widok zewnętrzny stłuczki szklanej powstającej podczas rozdrabniania mechanicznego. Powierzchnia większości cząstek jest pokryta luminoforem

It comes out from that pictures analysis that such glass particles surface still is covered with luminophor. Such a crushing mechanism makes that besides the part of the glass originally covered with luminophor also all other parts of the cullet becomes plentifully covered with luminescent material.

Such a cullet is subjected to principal comminution realized inside hydro-jet mill and then is separated inside hydro-cyclone. Humid form of the cullet is then lower through the bottom hole of the cyclone and goes directly to the container. Technological water is filtered off that container and after drying the cullet may be periodically directed for processing to the glass-house.

Outer view of produced this way glass cullet (Fig. 11) shows that it doesn't includes luminophor, which was washed out during that comminution.

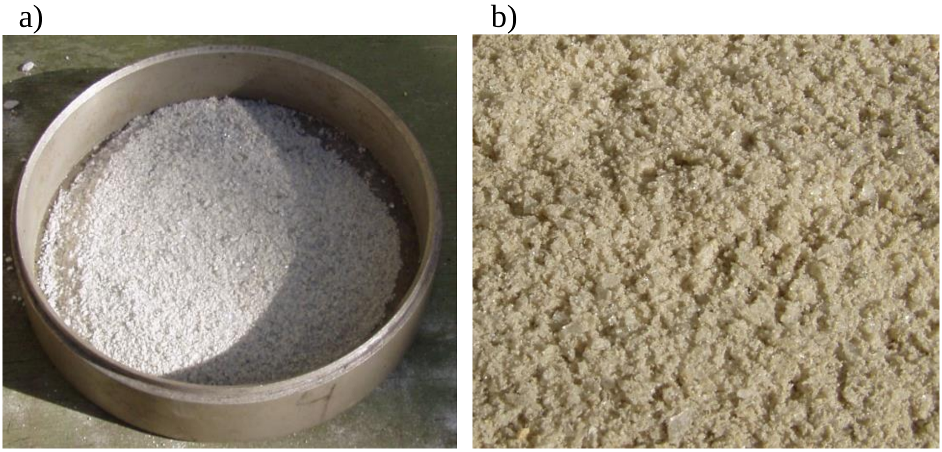


Fig. 11. Outer view of the glass cullet produced inside water-jet mill
Rys. 11. Widok zewnętrzny stłuczki szklanej powstającej w młynie hydrostrumieniowym

Confirmation for that can also be SEM images showing out details of such glass particles surface, presented in Fig. 12. These are exemplary images of particles obtained for different test conditions corresponding with respective distributions of glass particles, previously presented in Fig. 5–8.

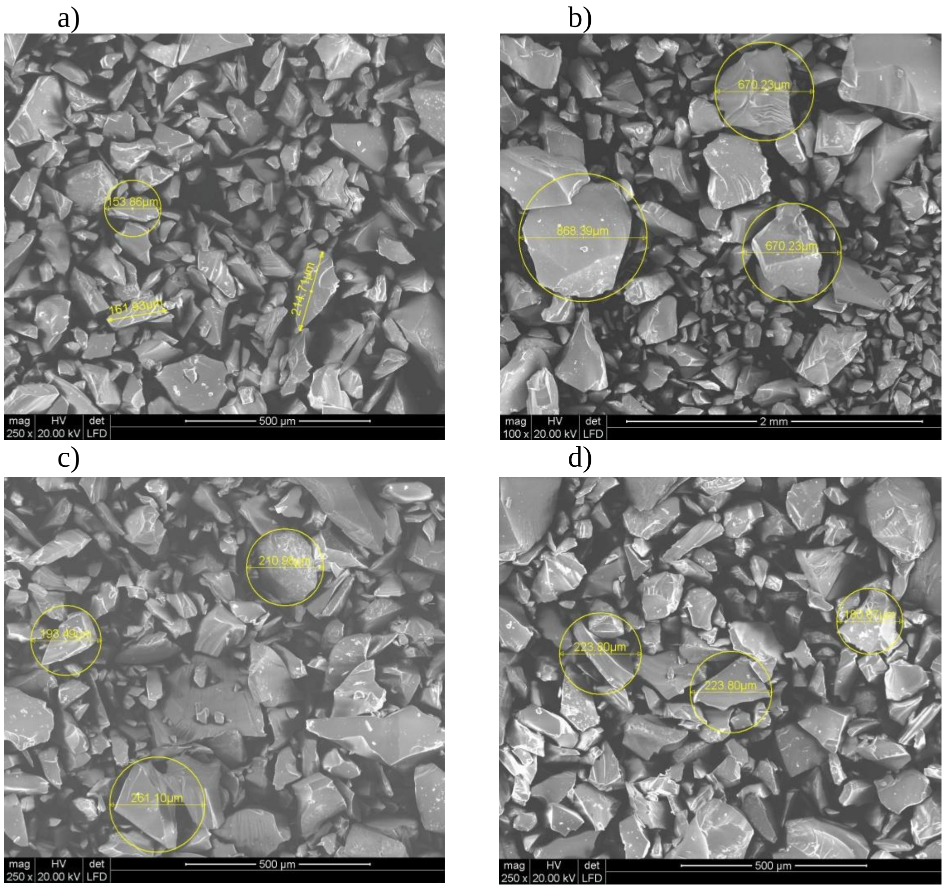


Fig. 12. SEM images of glass particles comminuted inside hydrojetting mill realized for different test conditions: a – d_w=0.7 mm, d_{h1}=2.4 mm, s=10 mm, p=42 MPa; b – d_w=0.7 mm, d_{h1}=2.4 mm, l=200 mm, s=10 mm, p=42 MPa; c – d_w=1.0 mm, d_{h1}=2.4 mm, s=10 mm, p=42 MPa; d – d_w=1.0 mm, d_{h1}=2.4 mm, l=200 mm, s=10 mm, p=42 MPa;

Rys. 12. Obrazy SEM cząstek szkła rozdrabnianego w młynie hydrostrumieniowym w r różnych warunkach: a – d_w=0,7 mm, d_{h1}=2,4 mm, s=10 mm, p=42 MPa; b – d_w=0,7 mm, d_{h1}=2,4 mm, l=200 mm, s=10 mm, p=42 MPa; c – d_w=1,0 mm, d_{h1}=2,4 mm, s=10 mm, p=42 MPa; d – d_w=1,0 mm, d_{h1}=2,4 mm, l=200 mm, s=10 mm, p=42 MPa;

4.2. Luminophor particles surface

During hydro-jetting comminution of glass particles obtained during mechanical crushing of luminescent lamps, the water jet washes out luminophor powder from the lamp, receiving white color (Fig. 13). It results from densification of luminophor suspension (Fig. 14).

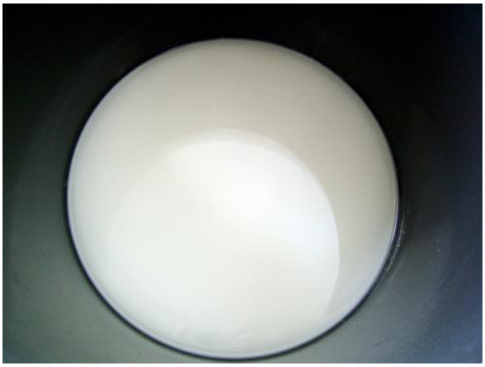
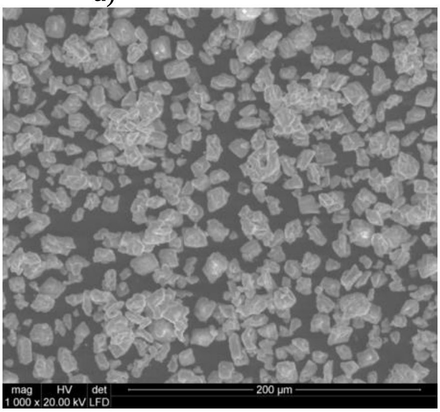


Fig. 13. Water suspension of luminophor particles (white color)
Rys. 13. Wodna zawiesina cząstek luminoforu (w kolorze białym)

a)



b)

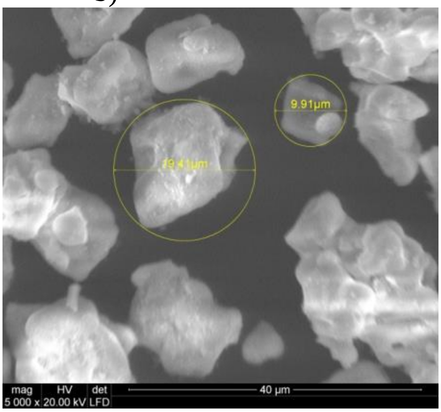


Fig. 14. SEM images of luminophor particles washed out during glass comminution inside hydro-jet mill
(d_w=0.7 mm, d_{h1}=2,4 mm, s=10 mm, p=42 MPa)
Rys. 14. Obrazy SEM cząstek luminoforu wypłukanych podczas rozdrabniania szkła w młynie hydrostrumieniowym
(d_w=0.7 mm, d_{h1}=2,4 mm, s=10 mm, p=42 MPa)

During SEM tests of luminophor particles surface, washed out in hydro-jetting comminution, no important quality differences in regard to powder of new luminophor were found.

5. Process of luminescent lamps utilization

Basing on the results of realized own experiments, a new original method of utilization of luminescent lamps with high-pressure water jet have been developed (Fig. 15).

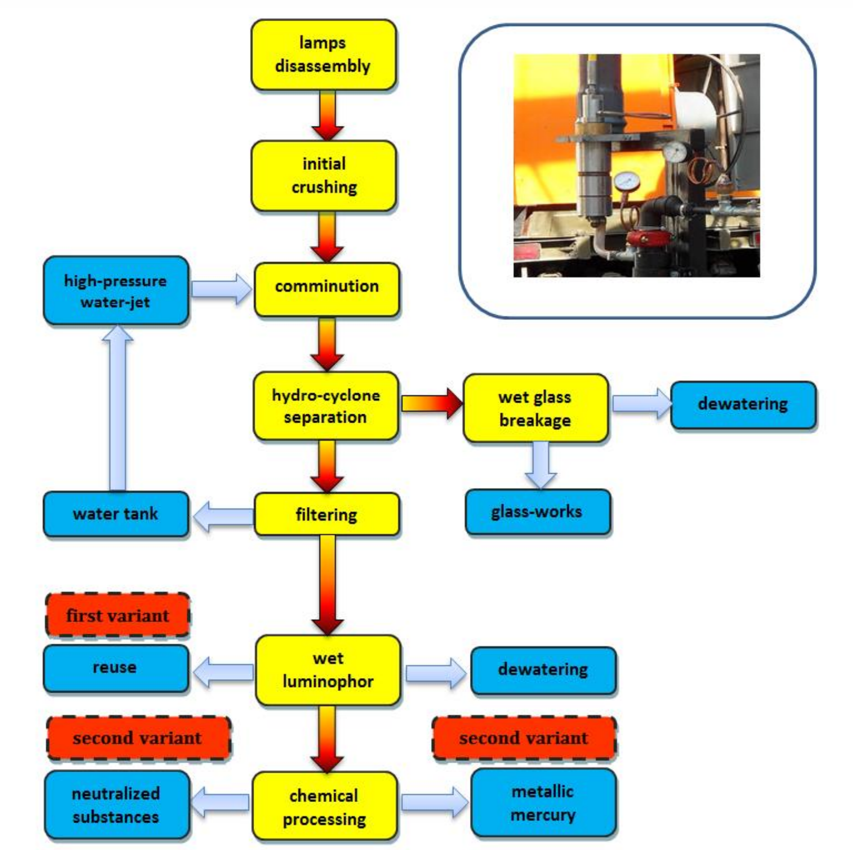


Fig. 15. Technology outline of luminescent lamps utilization
Rys. 15. Zarys technologii utylizacji lamp luminescencyjnych

Description of respective technological operations was presented in chapter 2. Some additional discussion needs a sample of humid luminophor, which according to Fig. 1 is collected in hermetic container 7. After drying, it is tested chemically, where the quality is evaluated in order to choose it further destination. The highest quality certificate of the luminophor allows its reuse while lower quality product needs additional chemical treatment improving its properties. The lowest quality luminophor is converted during pyrolysis into metallic mercury and other fully neutralized substances which can be safely treated as awaste for storage.

Basing on so far experience one can evaluate that high-pressure water jet can be used for such lamps utilization and it is very profitable considering ecological aspects. Therefore it gives real chance for practical implementation of the method.

6. Conclusions

Presented results of luminescent lamps utilization process, given in the form of luminescent material quality and glass comminution with high-pressure water jet technique, let to formulate the following important conclusions of general character:

- The most favorable distributions of glass particles comminuted in water-jet mill can be obtained for single homogenizing nozzle without any pipe extenders. For such conditions (d_w=0.7 mm) the cullet is comminuted in the most efficient way (Q_c=2.65 g/s) producing relatively large particles while the same production realized for larger nozzle holes (d_w=1.0 mm) gives over twice smaller efficiency (Q_c=1.12 g/s), ensuring the same time smaller cullet particles.
- Application of pipe extender (l=200 mm) for homogenizing nozzle causes more uniform distribution of glass size fractions, leading the same way to considerably limited effectiveness of the milling.
- The most often comminution fractions of glass are the range of 200–400 μm, for water-jet mill equipped with d_w=0.7 mm and giving respectively the range of 150–300 μm, for water-jet mill equipped with nozzle type d_w=1.0 mm.
- Amount of approx. 90% of glass is comminuted after the first stage using the mill equipped with single homogenizing nozzle without

any extenders inside, and these particles are the range not exceeding 550 μm (for d_w=0.7 mm), while using of nozzle type d_w=1.0 mm, such particles size contains in the range 0–400 μm. Analogical particles size for the cullet generated in water-jet mill equipped with nozzle pipe extender contains respectively in the range of: 0–600 μm for d_w=0.7 mm and 0–450 μm for d_w=1.0 mm.

- After mechanical comminution of luminescent lamps one can obtain glass particles which surface is still covered with luminophor.
- Comminution of such cullet using high-pressure water jet simultaneously causes that luminophor becomes washed out causing the same way that such cleaned cullet can be directed for further processing to the glass-work.
- Washed out particles of luminophor are not comminuted noticeably for water pressure p=42 MPa. Even up to 50% of luminophor being washed out is the size range not exceeding 15 μm, while 90% of these particles are sizes below 36 μm.
- There is no distinct quality difference between luminophor recovered from the process and luminescent powder used in a new lamp.
- Basing on realized research a technology outline of luminescent lamps have been elaborated including the most important technological operations.
- The quality of luminescent material recovered in utilization process decides of its potential usage. Good quality can be reused without any limitations while worse one needs additional chemical treatment that regenerates its properties. The worst quality material needs to be thermally decompositioned into metallic mercury and neutralized substances, and then may be safely stored as a nontoxic technological waste.

Taking into account all above results one should evaluate developed apparatus and original method as very effective technique for high-pressure water jet luminescent lamps utilization.

Nomenclature

a, ā [mm] – unitary, mean size of coal particle,
d_{h1} [mm] – homogenizing nozzle diameter,
d_w [mm] – water nozzle diameter,
dQ3 [%] – frequency of unitary value occurrence of coal particle size,
l [mm] – homogenizing tube length,
p [MPa] – water jet pressure,
Q_c [g/s] – efficiency of hydro-jetting comminution,
s [mm] – the length of high-pressure water jetting.

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Utylizacja lamp luminiscencyjnych przy użyciu wysokociśnieniowej strugi wodnej

Streszczenie

W artykule przedstawiono efekty badań nad utylizacją lamp luminescencyjnych przy użyciu wysokociśnieniowej strugi wodnej. Zastosowanie strugi wodnej jako czynnika roboczego ogranicza aerację substancji szkodliwych dla otoczenia i zapewnia większą uniwersalność zastosowań tej metody. Wynika to z równoczesnego rozdrabniania szkła i wypłukiwania luminoforu, przez co kształt utylizowanych lamp nie ma większego znaczenia. Zaprezentowano w nim oryginalny sprzęt technologiczny i unikalną aparaturę pomiarową oraz odpowiednią metodykę badań.

Do rozdrabniania szkła dostosowano młyn hydrostrumieniowy pracujący w zakresie ciśnień 35–50 MPa i zużywający 0.4–1.0 dm^3/s wody, który rozdrabnia stłuczkę szklaną o wielkości cząstek 0.5–2 mm z wydajnością 0.56–2.65 g/s. Przeprowadzone badania wykazały zadawalającą przydatność tego urządzenia, wyposażonego w dyszę wodną d_w=1.0 mm i dyszę homogenizacyjną d_h=2.4 mm, do hydrostrumieniowego rozdrabniania szkła lampowego. Umożliwia ono wytwarzanie drobnoziarnistego tłucznia szklanego pozbawionego luminoforu, w którym najczęściej uzyskiwane są frakcje cząstek o wymiarach 150–300 μm, a 90% cząstek mieści się w przedziale wymiarowym 0–400 μm.

Na podstawie przeprowadzonych badań nie stwierdzono istotnych różnic jakościowych luminoforu wypłukiwanego według tej metody, gdyż przy stosowanych tu ciśnieniach wody, jego cząstki nie ulegają zauważalnemu rozdrobnieniu. Dzięki temu aż 50% cząstek wypłukiwanego luminoforu jest mniejsza od 15 μm, a 90% cząstek posiada wymiary nie przekraczające 36 μm. Po osuszeniu luminofor ten jest poddawany badaniom chemicznym, oceniającym jego jakość. Luminofor o jakości porównywalnej z nowym może być stosowany ponowne bez ograniczeń technologicznych. Przy nieco gorszej jego jakości stosuje się dodatkową obróbkę chemiczną poprawiającą jego właściwości. Luminofory o najgorszej jakości są na drodze pirolizy przetworzone na rtęć metaliczną i substancje zneutralizowane, stanowiące bezpieczny odpad technologiczny.

W artykule przedstawiono także zarys procesu utylizacji lamp luminescencyjnych opracowany na podstawie przeprowadzonych badań własnych. Ich wyniki upoważniają do oceny, że zastosowanie wysokociśnieniowej strugi wodnej do utylizacji takich lamp, jest bardzo korzystne ze względów ekologicznych. Stwarza to realną możliwość praktycznego zastosowania opracowanej metody.

Słowa kluczowe: utylizacja, lampy luminescencyjne, wysokociśnieniowa struga wodna
Key words: utilization, luminescent lamps, high-pressure water-jet