

Znižanje proizvodnih stroškov z regeneracijo bentonitnega peska (Študija primera)

Reduction of production costs via bentonite clay powder¹ reclamation (Case study)

Povzetek

Livarne, ki uporabljajo bentonitne peske, se srečujejo s težavami, kot je prekomerna količina peska v obtoku, kot tudi neprimerna granulacijska sestava peska, ki vsebuje prevelik delež finih frakcij in inertnih snovi. Obstaja visoka povezanost med finimi frakcijami in inertnimi snovi v pesku ter napakami na ulitkih, še posebej v obliki vključkov peska. Vzdrževanje ustrezne peščene mešanice je možno z ustrezno večjim osveževanjem, kar posledično pomeni, da količina peska v sistemu naraste preko skladiščnih zmogljivosti in ga je potrebno izločati iz sistema ter odvažati na deponijo. Alternativa takemu načinu pa je uvedba naprave za regeneracijo peska.

V raziskavi smo prikazali, da s primerno regeneracijo povratnega peska lahko inertne snovi in fine frakcije vzdržujemo na želeni ravni, pri manjši porabi peska. Poraba kremenčevega peska se je zmanjšala za slabih 40 %, temu primerno pa se je zmanjšala tudi poraba bentonita in črnine. Investicija v regeneracijo se povrne v manj kot 2 letih.

Ključne besede: regeneracija, bentonitni pesek, fine frakcije, odprane snovi, stroški, t-test

Summary

Foundries which utilize bentonite clay powders often face problems such as excessive sand quantities in circulation along with inadequate granular sand composition, i.e. sand that contains excessive fine fractions and inert substance proportions. There is a high correlation between fine fractions, inert substances in the sand and faulty castings, particularly in the form of sand inclusions. Maintaining a suitable sand mixture is possible via suitable refreshing. In turn, the quantity of system sand will surpass the available storage space and will need to be eliminated from the system and discarded at a landfill. An alternative to this is the introduction of a sand reclamation system.

In the study, we have shown that via suitable return sand reclamation, inert substance and fine fraction levels can be maintained and the sand consumption reduced. Silica sand consumption was decreased by just under 40%, and also resulted in the reduced consumption of bentonite clay and blacking. The reclamation investment should return within less than 2 years.

Keywords: reclamation, bentonite clay powder, fine fractions, leached substances, costs, t-test

1 Proizvajalec opreme loči med reclamation, kar obravnavamo in regeneration. Ker v slo. nismo našli ustrežnejšega izraza, uporabljamo termin regeneracija.

The equipment manufacturer differentiates between the terms reclamation, dealt with in this article, and regeneration. Since no equivalent exists in Slovene, the expression »regeneracija« has been used throughout.

1 Uvod

Formarska linija v obravnavani livarni ima zmogljivost 150 form/h. Velikost okvirjev 900 x 900 x 300/300 mm, s horizontalno delilno ravnino. Količina peska v skopljeni formi je cca. 700 kg, povprečna masa litine pa 25 kg, kar kaže na visoko razmerje pesek : litina (p/l).

Visoko razmerje p/l povečuje delež finih frakcij v pesku, kar posledično pomeni majhen delež izgub in zato manjšo možno osvežitev peska pri konstantni količini peska v sistemu. Drugače povedano, če bi pesek osveževali z deležem, s katerim bi zagotavljali primerno kakovost ulitkov, bi količina v sistemu naraščala in bi kmalu preseгла zmogljivost zalogovnikov. Težava finih frakcij v pesku je v tem, da povečujejo potrebo po vlagi - in to lahko do take mere, da se je zaradi oteženega formanja in posledično oteženega razpada na rešetki ne moremo privoščiti. Ugotovili smo, da na delež izmeta najbolj vplivata dve, v raziskavi [1] zajeti spremenljivki. Zelo visoka pozitivna linearna povezanost je med izmetom in deležem odpranih snovi v pesku. Med vsemi korelacijami ima ta najvišjo vrednost, katere faktor (R) je enak 0,804. Med drobnimi frakcijami peska in izmetom je visoka linearna povezanost. Vrednost faktorja (R) med deležem peska z granulacijo < 0,09 mm in izmetom je enaka 0,737, med deležem peska z granulacijo < 0,125 mm in izmetom pa je enaka 0,626.

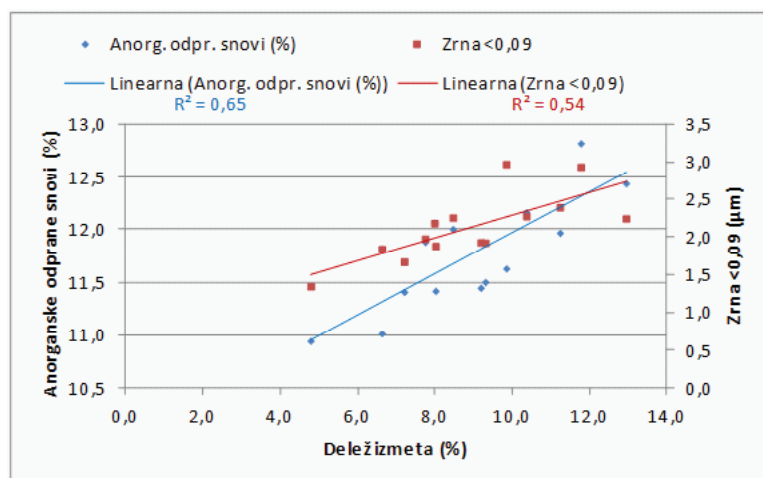
Delež odpranih snovi in finih frakcij (< 0,09 mm) se povečuje s kroženjem peska v sistemu. Če je razmerje p/l visoko, 20:1 in več, se delež odpranih snovi in finih frakcij stabilizira na zelo visoki ravni. Pri osveževanju sistema z 0,5 % dodatkom, se pesek v sistemu zamenja v cca. 1000 obratih, kar pomeni, da se dolgo zadržuje v sistemu in zdrobi do stopnje, ko se fine frakcije stabilizirajo na visoki ravni. Krajši

1 Introduction

The moulding line at the subject foundry has a capacity of 150 moulds/h. Moulds are sized 900x900x300/300 mm and have a horizontal joint face. A packed mould is composed of ca. 700kg sand while the mass of the average alloy totals to 25 kg, which is indicative of a high sand vs. alloy ratio (S/A).

A high S/A ratio increases the fine fraction proportions in sand. In turn, this leads to minimal losses as well as smaller refreshing sand volumes at constant sand system levels. To reiterate, if sand was refreshed via the proportion of sand which would guarantee the required casting quality, the system sand volume would soon grow out of control and exceed available storage capacities. The problem with fine sand fractions is that they in turn increase moisture requirements to the extent that mould production and subsequent breaking of moulds becomes extremely difficult. We have established that the rejection rate is most prominently affected by the two variables included in the study [1]. There exists an extremely high positive linear correlation between the rejection rate and the proportion of leached substances in the sand. Among all correlations, the highest values have been calculated for those with the factor (R) equalling 0.804. There also exists a high linear correlation between fine sand fractions and the rejection rate. The value of factor (R) between the proportion of sand sized <0.09 mm and rejection equals 0.737, while in case of sand grains <0.125 mm and rejections it totals to 0.626.

The proportion of leached substances and fine fractions (<0.09 mm) increases with the circulation of sand within the system. In case of a high S/A ratio (20:1 or higher), the proportion of leached substances and fine fractions is stable at a very high level. When



Slika 1: Povezanost odpranih snovi in finih frakcij kremenčevega peska z izmetom

Figure 1: Correlation between leached substances and fine silica sand fractions vs. rejection rate

čas zadrževanja peska v sistemu oziroma manjše število obratov peska pa posledično predstavlja nižji delež finih frakcij in odpranih snovi.

Vpliv finih frakcij na delež izmeta je viden na sliki 1. Determinacijski koeficient R^2 je srednje visok, tako da s spremenljivko »Zrna < 0,09« lahko pojasnimo 54 % variabilnosti izmeta.

Vpliv odpranih snovi na višino izmeta je prav tako prikazan na sliki 1. Determinacijski koeficient R^2 je visok, tako da s spremenljivko »Anorganske odprane snovi« pojasnimo 65 % variabilnosti izmeta.

2 Opis težave

Dejstvo je, da je nizek delež odpranih snovi in finih frakcij v pesku težko obvladovati. Deleži se spreminjajo v odvisnosti od spreminjanja razmerja p/l. Velja, da večje razmerje p/l povzroča nastajanje večjega deleža odpranih snovi ter finih frakcij in obratno. Za vzdrževanje želenega deleža odpranih snovi in finih frakcij moramo peščen sistem primerno osveževati. Pri visokem razmerju p/l (> 20:1), je to skoraj

refreshing the system with approx. 0.5% material, the sand within the system will be replaced in ca. 1000 cycles. This means that the sand will remain within the system for extended periods and become crushed to the extent where high levels of fine fractions become prevalent. In turn, shorter system sand times and reduced number of cycles will lead to a smaller proportion of fine fractions and leached substances.

The impact of fine fractions on rejection rates is shown in Figure 1. The R^2 coefficient of determination is medium high, which means that the »Grain < 0.09« variable should explain the 54% rejection variability.

The impact of leached substances vs. rejection rate is shown in Figure 1. The R^2 coefficient of determination is high, which means that the »Inorganic leached substances« variable should explain the 65% reject variability.

2 Problem description

It is well known that maintaining a low rate of leached substances and fine fractions in sand is notoriously difficult. The proportions

nemogoče, ne da bi izločali določeno količino peska iz sistema, ker bi sicer količina peska v obtoku presegla razpoložljive skladiščne zmogljivosti. Rešitev je možno iskati tudi v primernem odpraševanju povratnega peska, vendar le ob primerno nizki vlagi (< 2%), kar pa je pri visokem razmerju p/l spet težko doseči.

Konkretno rešitev za zmanjšanje deleža odpranih snovi in finih frakcij, ki so povezane z investicijami, bomo prikazali v nadaljevanju.

2.1 Cilj projekta

Izbrati primerno opremo za regeneracijo peska, s katero bi zagotavljali osveževanje v takem obsegu, da bi pokrivali samo izgube peska po naravni poti, kar pomeni samo izgube s peskanjem ulitkov.

2.1.1 Primarni cilj

Peščeni sistem bi osveževali samo toliko, da bi pokrivali izgube, kar pomeni, da bi bil dodatek novega peska 5 kg, namesto sedanjih 8 kg/mešalec. Manjši porabi kremenčevega peska bi sledila tudi manjša poraba črnine in bentonita.

2.1.2 Sekundarni cilji

Delež odpranih snovi bi moral ostati na enaki ravni ali biti celo nižji. Delež drobnih frakcij kremenovih zrn bi prav tako moral ostati vsaj na enaki ravni, če ne še nižji. Delež ulitkov z napakami se ne bi smel povečati, ostati mora vsaj na enaki ravni, kot pred uvedbo regeneracije.

2.2 Izbor in testiranje opreme

Zastavljene cilje smo poskušali doseči z investicijo v mehansko regeneracijo peska.

change based on the S/A ratio. Namely, a higher S/A ratio will generate a higher proportion of leached substances and fine fractions, and vice versa. In order to maintain the leached substances and fine fraction proportions, the foundry sand system must be suitably maintained. With a high S/A ratio (>20:1), this could prove virtually impossible without first removing part of the sand from the system. Otherwise, the total quantity of sand used in the foundry would soon exceed the available storage capacity. Another solution would be the suitable dedusting of return sand at low moisture levels (<2%), which could prove quite difficult with a high S/A ratio.

The concrete solution which would reduce the proportion of leached substances and fine fractions connected to the investments is described below.

2.1 Project objectives

Selection of suitable sand reclamation equipment which would ensure the recovery of sand to the extent that would only necessitate the refreshing of sand lost naturally, i.e. via casting sand blasting.

2.1.1 Primary objective

The sand system would only be refreshed to the extent of covering losses. This means that only 5kg of new sand would need to be added instead of the current 8kg/mixer. The decreased silica sand consumption would also result in a decrease in blacking and bentonite clay use.

2.1.2 Secondary objective

Maintain or reduce the level of leached substances. The proportion of fine silica

Tabela 1: Rezultati testiranja peska [3]**Table 1:** Sand testing results [3]

Batch number / Številka šarže	A-1		A-2	
Nozzle gap setting / Nastavitev šob	6		6	
Scrub rate (kg/hr/cell) / Storilnost regene.	900		1125	
Plenum negative (mm) / Presipi nastavitev	38		38	
Total material (kg) / Celotna količina	135	100,00%	134	100,00%
DMaterial Charged in Reclaim. / Dejansko	135	100,00%	134	100,00%
Total reclaimed (kg) / Regenerirano	101	75,25%	108	80,87%
Total losses (kg) / Celotne izgube	33	24,75%	26	19,13%
Reclaimer yield / Izkoristek		75,25%		80,87%
LOI reduction / Znižanje žaroizgub		60,22%		42,92%
AFS clay reduction / Znižanje odpranega		55,25%		43,05%
M.B. clay reduction / Znižanje bentonita		55,07%		40,58%

Izbrali smo opremo SIMPSON ProClaim, ki ga zastopa Siapro [2], z zmogljivostjo do 5 t/h, kar je najmanjša, ki jo ponujajo, in bi bila za naše potrebe povsem primerna. Poslan je bil vzorec 1000 kg peska na testiranje v SIMSON, kjer so po opravljeni regeneraciji izdelali poročilo (tabela 1), ki je ustrezalo zahtevam.

Začeli smo s časi obratovanja, kot so navedeni spodaj, in pri takem obratovanju zbirali podatke za analizo učinkovitosti delovanja regeneracije.

Čas obratovanja regeneracije	7 h/dan
Čas doziranje peska v napravo	4 h/dan
Čas regeneriranja	3 h/dan
Vstopna količina peska	7000 kg (340 kg/h)
Izstopna količina	6685 kg
Odpadek	315 kg oz. 5%

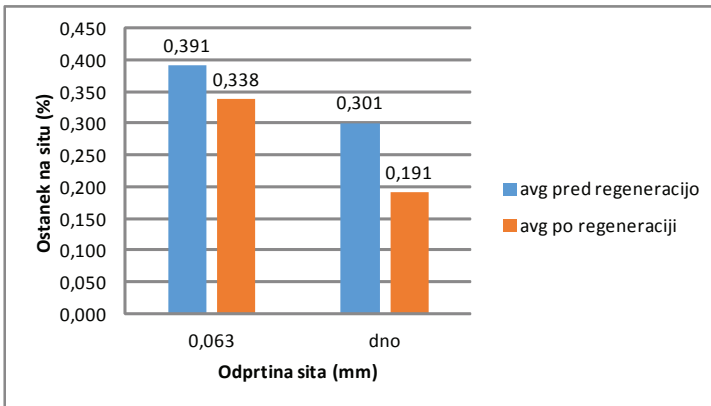
Preverjali smo zmanjšanje deleža drobnih frakcij kremenčevega peska, žaro izgube in odprane snovi, na izstopu iz regeneracije. Na sliki 2 vidimo, da se je delež ostanka na situ 0,063 mm zmanjšal

sand fractions should be maintained or even reduced. The proportion of faulty castings should not increase. Instead, it should at a minimum correspond to the levels before the introduction of reclamation.

2.2 Equipment selection and testing

The means to achieve the defined objectives is an investment into a mechanical sand reclamation system. Selected was equipment by SIMPSON ProClaim represented by Siapro [2] with a capacity of up to 5t/h, that is the lowest capacity available, which is perfectly suitable in light of our requirements. 1000 kg sand was despatched to SIMPSON for testing where a report in line with the requirements was drawn up following reclamation.

Initially, operation times as set out below were used. Based on such operations, data was collected in order to carry out a reclamation efficiency analysis.



Slika 2: Delež podzrna v povratnem pesku pred in po regeneraciji

Figure 2: Undersized grains in return sand before and after regeneration

za dobrih 13 %, medtem ko se je delež na dnu zmanjšal za dobrih 36 %.

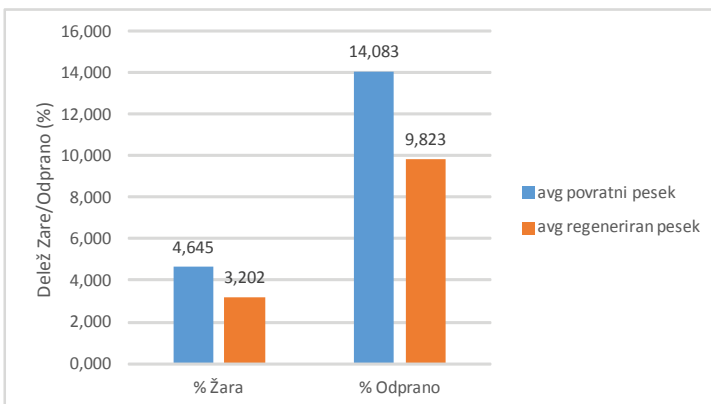
Na sliki 3 je vidna sprememba žaro izgub, ki so se znižale za dobrih 30 %, za enak delež pa so se znižale tudi odparane snovi. Tako prečiščen pesek se vrača v obtok in znižuje vrednosti obravnavanih parametrov v peščenem sistemu na želeno raven.

Odvisto od naših potreb lahko z regeneracijo očistimo pesek do različne stopnje. Na sliki 4 vidimo bentonitni pesek po razbitju forme na povratni liniji. Nekatera zrna so v obliki aglomeratov, ki pa se z

Reclamation operation time	7 h/daily
Time required to add sand into equipment	4 h/day
Reclamation time	3 h/daily
Entry sand quantity	7000 kg (340 kg/h)
Exit sand quantity	6685 kg
Scrap	315 kg or 5 %

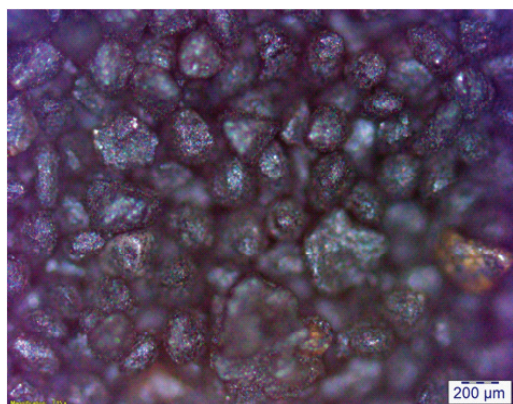
Investigated was the decrease of fine silica sand proportions, LOI and leached substances after reclamation. Figure 2 shows that the 0.063 mm sieve residue was reduced by more than 13 % while passing residue collected at the bottom was reduced by more than 36 %.

Figure 3 illustrates the change in LOI, which was reduced by more than 30%,



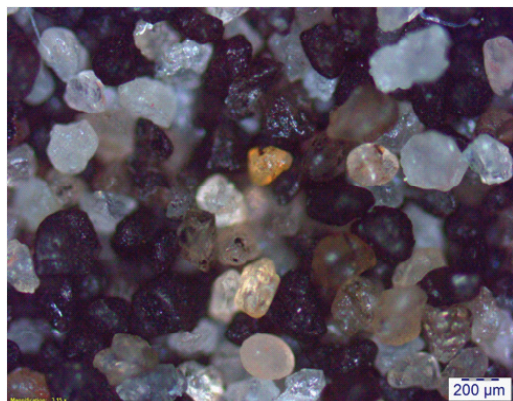
Slika 3: Sprememba žaro izgub in odpranih snovi na povratnem pesku

Figure 3: Change in LOI and leached substances in return sand



Slika 4: Bentonitni pesek ki vstopa v regeneracijo

Figure 4: Bentonite clay powder entering reclamation



Slika 5: Očiščen pesek iz regeneracije, ki se vrača v obtok

Figure 5: Purified reclaimed sand returning to circulation

regeneracijo razbijejo in ponovno dobimo posamezna zrna peska.

Iz regeneracije prihaja pesek, ki je v veliki meri očiščen bentonitnih oblog, kot tudi prašnih frakcij. Na sliki 5 je videti velik delež kremenovih zrn, ki so popolnoma očiščena bentonitnih (lahko tudi oolitiziranih) oblog. Kremenova zrna so po regeneraciji manj oglata, nekatera so tudi zaobljena, kar je

that is the same proportion as leached substances. The purified sand is then returned into circulation and reduces the subject parameters of the sand system to the desired levels.

In light of requirements, the reclamation process can be used to purify sand to varying degrees. Figure 4 illustrates bentonite clay powder in the return line after mould breaking. Some grains will take on the shape of agglomerates which, via reclamation, will break and again form individual grains of sand.

Reclaimed is sand which has been to a large extent purified of bentonite clay particles as well as powder fractions. Figure 5 shows a large proportion of silica sand grains completely purged of bentonite clay particles. Following reclamation, silica sand grains lose its angular shape and some even become round. The latter is the most suitable shape of silica sand grains since their surface area is smaller than that of angular grains.

3 Methodology

The hypotheses will be tested while observing the fact that the addition of silica sand was decreased from a total of 8 kg/mixer to 5 kg/mixer. In turn, this saw a proportional reduction in the added bentonite clay and blacking as shown in Figure 6.

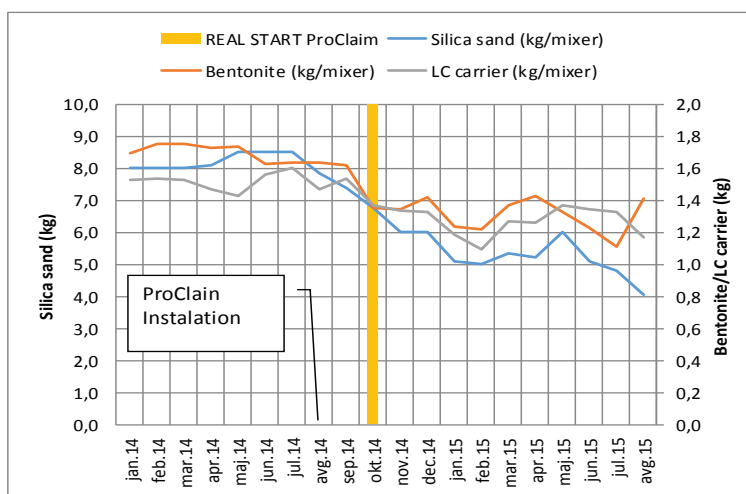
Based on the defined objectives, the following hypotheses have been set:

The proportion of leached substances² after reclamation ($\mu_{1,2}$) is equal to the proportion ($\mu_{1,1}$) before the introduction of sand reclamation.

Proportion of grains size below $90\mu\text{m}$ reclamation ($\mu_{2,2}$) is equal to the proportion of grains ($\mu_{2,1}$) before the introduction of reclamation.

Slika 6: Gibanje dodatkov/mešalec pred in po uvedbi regeneracije

Figure 6: Flow of additives/mixer before and after the introduction of reclamation



najprimernejša oblika kremenovih zrn, ker imajo manjšo površino od oglatih.

3 Metodologija

Hipoteze bomo preverili ob dejstvu, da smo dodatek kremenčevega peska zmanjšali z 8 na 5 kg/mešalec. Proporcionalno se je znižal tudi dodatek bentonita in črnine (nosilca svetlečega C), kar je prikazano na sliki 6.

Iz zastavljenih ciljev bomo postavili naslednje hipoteze:

Delež odpranih snovi po regeneraciji ($\mu_{1,2}$) je enak deležu ($\mu_{1,1}$) pred uvedbo regeneracije.

$$H_0^{(1)}: \mu_{1,1} - \mu_{1,2} = 0$$

$$H_1^{(1)}: \mu_{1,1} - \mu_{1,2} \neq 0$$

Delež zrn pod 90 μm po regeneraciji ($\mu_{2,2}$) je enak deležu zrn ($\mu_{2,1}$) pred uvedbo regeneracije.

$$H_0^{(2)}: \mu_{2,1} - \mu_{2,2} = 0$$

$$H_1^{(2)}: \mu_{2,1} - \mu_{2,2} \neq 0$$

- 2 Obravnavali bomo celokupne in mineralne (anorganske) odprane snovi.
Analysis of total and mineral (inorganic) leached substances.

Rejection rate after reclamation ($\mu_{3,2}$) is equal to the rejection rate ($\mu_{3,1}$) before the introduction of reclamation.

The hypotheses will be subjected to a t-test used to compare sample arithmetic means.

The t-test is a statistical method common in every type of research. There exist three variations of the t-test: the one-sample t-test, independent two-sample t-test and the dependent t-test (for paired samples). Most commonly employed is the independent two-sample t-test, which is used to establish whether statistically significant differences between two independent samples exist. [4]

3.1 Data analysis

The subject data represent the average monthly bentonite clay powder variables and examined parameters.

Delež izmeta po regeneraciji ($\mu_{3,2}$) je enak deležu izmeta ($\mu_{3,1}$) pred uvedbo regeneracije.

$$H_0^{(3)}: \mu_{3,1} - \mu_{3,2} = 0$$

$$H_1^{(3)}: \mu_{3,1} - \mu_{3,2} \neq 0$$

Hipoteze bomo preverili s t – testom, ki se uporablja za primerjavo aritmetičnih sredin vzorcev. T-test je zelo pogosto uporabljena statistična metoda v vseh vrstah raziskav. Poznamo tri vrste tega testa, t-test za en vzorec, za neodvisne vzorce in pa za odvisne vzorce (parni t-test). Najpogosteje se uporablja test za neodvisne vzorce, kjer ugotavljamo, ali obstajajo statistično pomembne razlike med dvema neodvisnima skupinama.[4]

3.1 Analiza podatkov

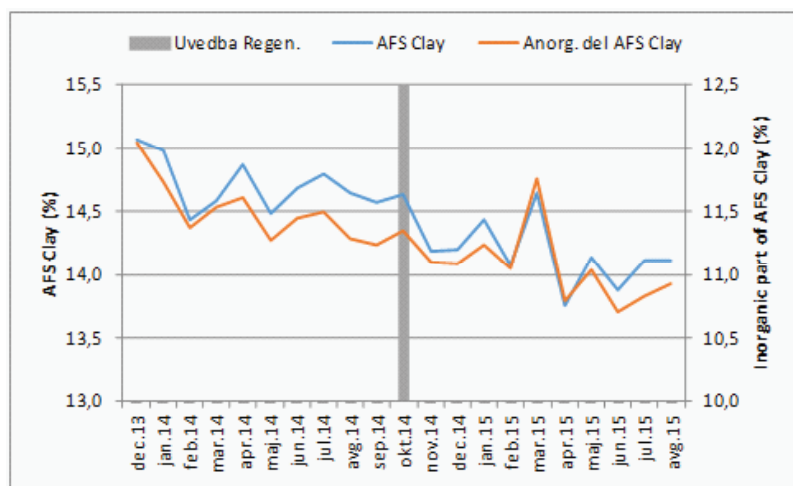
Vsi obravnavani podatki predstavljajo mesečne povprečne vrednosti spremenljivk oziroma opazovanih parametrov bentonitnega peska.

Na sliki 7 je prikazano gibanje deleža odpranih snovi za obdobje pred in po uvedbi regeneracije. Stolpec predstavlja termin začetka delovanja regeneracije.

Figure 7 depicts the movement of leached substance proportions before and after the introduction of reclamation. The column represents the date of start of the reclamation process. The total proportion of leached substances along with mineral substances has decreased with the introduction of reclamation, and will be tested via the t-test.

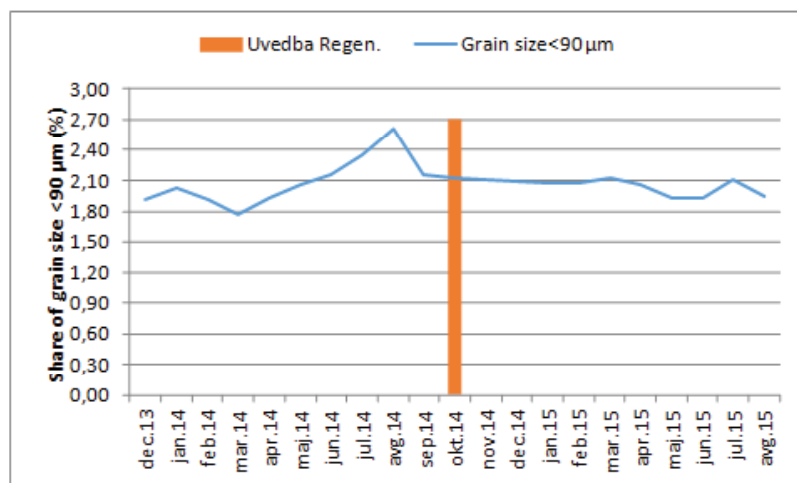
Figure 8 illustrates the movement of silica sand grain proportions which have passed through the 90 μ m sieve during the sieve analysis. We can establish that after the introduction of reclamation, the proportion of fine fractions is more uniform. Before the introduction of reclamation, sample variance was calculated at 0.0599, while after its introduction it significantly decreased to 0.0061.

The rejection movement is depicted in Figure 9, where »izm« stands for the total rejection and »nln« the proportion following machining. Any faults apparent following machining can be attributed primarily to sand inclusions. However, a smaller approx. 5 % part is constituted by so-called »pinholes«, surface irregularities resulting from the expansion of the sand mould and slag inclusions. Following the



Slika 7: Gibanje deležev odpranih snovi v bentonitnem pesku

Figure 7: Movement of leached substance proportions in bentonite clay powder



Slika 8: Gibanje deleža zrn kremenčevega peska < 90 µm

Figure 8: Silica sand grains <90 µm proportions movement

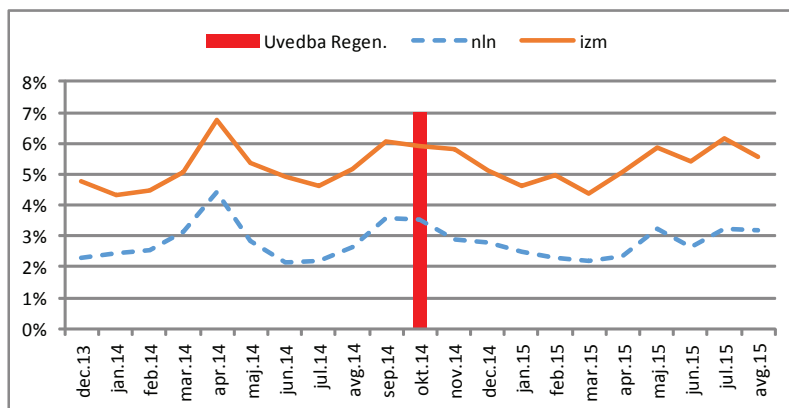
Delež celokupnih odpranih snovi kot tudi anorganskega dela je po uvedbi regeneracije manjši, kar bomo preverili s t-testom.

Na sliki 8 vidimo gibanje deležev zrn kremenčevega peska, ki so pri sejalni analizi padla skozi sito z odprtino 90 µm. Ugotovimo lahko, da je delež finih frakcij po uvedbi regeneracije bolj konstanten. Varianca vzorca pred uvedbo regeneracije je 0,0599, po uvedbi pa se je močno zmanjšala na 0,0061.

introduction of reclamation, the rejection variability was reduced substantially. Before the introduction of reclamation, sample variance was calculated at 0.554, while after its introduction it was reduced to 0.318.

Alongside the variables contained in the hypotheses, we have also completed the analysis of two further variables, namely sand moisture content and active clay.

Figure 10 shows that the content of active clay in sand trend is nearly parallel to the abscissa while the required moisture



Slika 9: Gibanje deleža in izmetnih ulitkov

Figure 9: Proportions and rejected castings movements

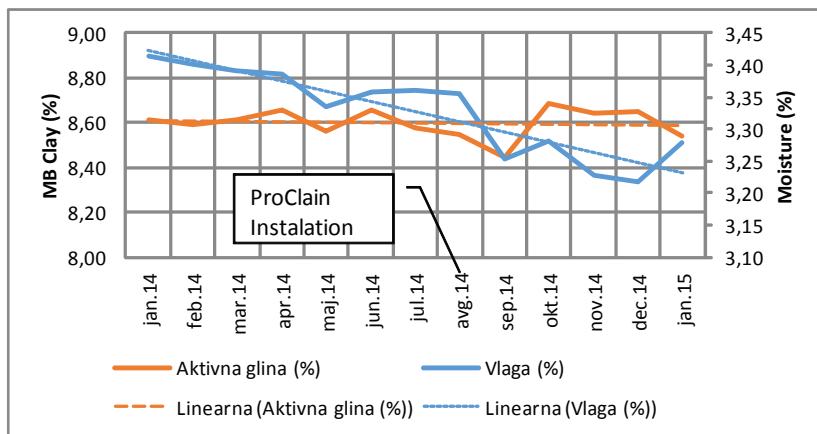
Gibanje izmeta je vidno na sliki 9, kjer »izm« predstavljaja celokupni izmet, »nln« pa delež po mehanski obdelavi. Napake, vidne po mehanski obdelavi, so v glavnem vključki peska, le manjši delež, približno 5 %, predstavljajo »pinhole«, sledi površinskih napak zaradi ekspanzije peščene forme in vključki žindre. Po uvedbi regeneracije se je variabilnost izmeta zmanjšala. Varianca vzorca pred uvedbo regeneracije je 0,554, po uvedbi pa se je zmanjšala na 0,318.

Poleg spremenljivk, ki so bile zajete v hipotezah, smo s časovno vrsto analizirali

trend is on the decline. The levels of active clay have therefore been maintained while the required moisture levels have decreased. This should be attributed to the leached substances proportion and verified via the t-test.

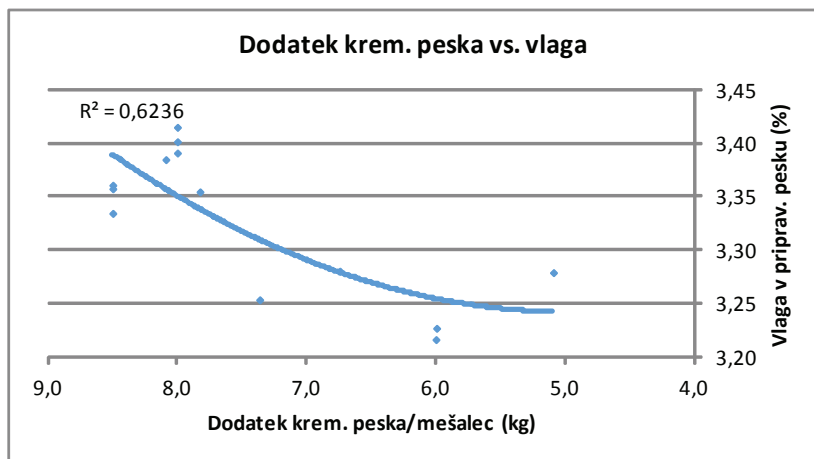
The regression analysis yielded two variables, moisture and added silica sand. A moderate correlation with the coefficient of determination $R^2 = 0.624$ was established as shown in Figure 11.

Caution must be exercised in the interpretation of the moisture – added silica sand connection. Namely, it would



Slika 10: Gibanje vlage in aktivne gline

Figure 10: Moisture and active clay movements



Slika 11: Povezanost med dodatkom novega peska in potrebno vlago v pesku pri obratovanju regeneracije.

Figure 11: Correlation between added sand and required sand moisture in the reclamation process.

še spremenljivki, vlago v pesku in aktivno glino.

Na sliki 10 vidimo, da je trend deleža aktivne gline v pesku skoraj vzporeden z absciso, medtem ko je trend potrebne vlage v padanju. Aktivna glina je torej ostala na enaki ravni, potreba po vlagi pa se je zmanjšala, kar lahko pripišemo zmanjšanju deleža odpranih snovi, kar bomo preverili s t-testom.

Z regresijsko analizo smo obdelali spremenljivki: vlaga in dodatek kremenčevega peska. Pokazala se je srednje visoka povezanost z determinacijskim koeficientom $R^2 = 0,624$, kar je prikazano na sliki 11.

Pazljivi moramo biti pri interpretaciji odnosa vlaga – dodatek kremenčevega peska. Napačna bi bila splošna trditev, da se s povečevanjem dodatka kremenčevega peska povečuje potreba po vlagi v pesku. Poudariti moramo, da ta odnos velja samo takrat, kadar pesek regeneriramo, in tako zmanjšujemo frakcije, ki vežejo veliko vode. Z grafom (slika 11) lahko pokažemo na dejansko zmanjšanje potrebe po vlagi pri istočasnem manjšem dodatku kremenčevega peska, ki je vzdržen, zato ker z regeneracijo lahko obvladujemo snovi v pesku, ki vežejo velike količine vode.

3.2 Testiranje hipotez

Hipoteze smo preverili z analitičnim orodjem v Excelu. V tabeli 2 so podani rezultati t – testov odpranih snovi, tako celokupnih, kot anorganskega dela in finih frakcij kremenčevega peska. Za vsako od spremenljivk so podani izračuni pred in po uvedbi regeneracije - in sicer aritmetične sredine (Mean), varianca (Variance), numerus (Observations) in ostale statistike. Za vse pare vzorcev smo zastavili hipoteze,

be erroneous to claim that in general, the addition of silica sand increases sand moisture requirements. It should be pointed out that this correlation is only valid when sand is reclaimed and in turn proportions of fractions which absorb plenty of water are reduced. A chart (Figure 11) is used to demonstrate the actual reduction of moisture requirements simultaneously with reduced quantities of added silica sand, making it sustainable since the reclamation process can be used to control the substances in the sand that absorb high quantities of water.

3.2 Hypotheses testing

The hypotheses were verified using MS Excel analytical tools. Table 2 contains leached substances t-test results, totals as well as inorganic proportions as well as fine silica sand fractions. For each of the variables, calculations before and after the introduction of reclamation are indicated, i.e. arithmetic mean (Mean), variance (Variance), number of measurements (Observations) and other statistical values. For each of the sample pairs, the mean difference was hypothesized.

In terms of leached substances (AFS Clay), when comparing t-Stat to t Critical two tail, it can be established that it is true in both cases, that $t\text{-Stat} > t\text{ critical two tail}$ and the $P\text{ two tail} < 0.5$, meaning that the hypothesis can be rejected. The same is true for the inorganic portion of leached substances. Differences between the arithmetic means of samples before and after the introduction of reclamation do exist, as was already inferred based on the chart in Figure 7.

Similarly, sand fractions $<90\mu\text{m}$ values from Table 1 can also be compared. In this case, the $t\text{-stat} < t\text{ critical two tail}$, and $P\text{ two tail} > 0.5$, meaning the hypothesis

da med aritmetičnima sredinama ni razlik (Hypothesized Mean Difference).

Če pri odpranih snoveh (AFS Clay) primerjamo t_{Stat} z $t_{Critical two tail}$, ugotovimo, da je v obeh primerih $t_{Stat} > t_{Critical two tail}$ in je $P_{two tail} < 0,5$, kar pomeni da hipotezo zavrnemo. Enako velja za anorganski del odpranih snovi. Med aritmetičnimi sredinama vzorcev pred in po uvedbi regeneracije so razlike, kar smo domnevali že iz grafa na sliki 7.

Podobno lahko primerjamo vrednosti iz tabele 2 za frakcije peska $< 90 \mu m$. V tem primeru pa je $t_{Stat} < t_{Critical two tail}$ in je $P_{two tail} > 0,5$, kar pomeni, da hipotezo sprejmemo. Med aritmetičnima sredinama vzorcev pred in po uvedbi regeneracije ni razlik, kar bi lahko sklepali iz grafa na sliki 8.

is confirmed. Differences between the arithmetic means of samples before and after the introduction are null, as already could have been inferred based on chart in Figure 8.

In terms of the total rejection rate, the absolute $t_{stat} < t_{Critical two tail}$, and $P_{two tail} > 0,5$, meaning the hypothesis can be confirmed. There are no differences between the total rejection rate arithmetic means before and after the introduction of reclamation. The same can be inferred for the rejection rate following machining. Even though no statistically significant differences have been established, minor changes remain apparent. The total rejection was adjusted by the 101.9 index, and rejection following machining by the index 96.4.

Tabela 2: Rezultati t - testov za odprane snovi in fine frakcije kremenčevega peska

Table 2: T-test results for leached substances and fine silica sand fractions

t-Test: Two-Sample Assuming Unequal Variances						
	AFS Clay Before Reclaim	AFS Clay After Reclaim	Inorg. part AFS Clay Before Reclaim	Inorg. part AFS Clay After Reclaim	Grain<90 μm Before Reclaim	Grain<90 μm After Reclaim
Mean	14,712525	14,1566467	11,5046667	11,0535609	2,08735833	2,04171516
Variance	0,04358271	0,06285378	0,05991536	0,08675772	0,06061343	0,00586115
Observations	10	10	10	10	10	10
Hypothesized Mean Difference	0		0		0	
df	17		17		17	
t Stat	5,38808548		3,72480155		0,55981954	
P(T<=t) one-tail	0,000025		0,00084231		0,29341067	
t Critical one-tail	1,73960672		1,73960672		1,79588481	
P(T<=t) two-tail	0,000049		0,00168462		0,58682135	
t Critical two-tail	2,10981556		2,10981556		2,20098516	

Tabela 3: Rezultati t - testa za celokupni izmet in izmet po mehanski obdelavi**Table 3:** Total rejection rate and rejection rate following machining t-test

t-Test: Two-Sample Assuming Unequal Variances				
	izm_before	izm_after	nln_before	nln_after
Mean	5,2%	5,2%	2,8%	2,7%
Variance	5,537E-05	3,181E-05	5,1382E-05	1,59351E-05
Observations	10	10	10	10
Hypothesized Mean Difference	0		0	
df	17		17	
t Stat	-0,4896546		0,33071411	
P(T<=t) one-tail	0,3153184		0,37287897	
t Critical one-tail	1,7396067		1,76131012	
P(T<=t) two-tail	0,6306369		0,74575794	
t Critical two-tail	2,1098156		2,14478668	

V tabeli 3 so prikazani rezultati t – testa za celotni izmet »izm« in delež izmeta, ki je viden po mehanski obdelavi »nln«.

4 Investment eligibility

The investment into reclamation will generally return in a relatively short period.

Tabela 4: Ekonomsko ovrednotenje investicije v regeneracijo bentonitnega peska**Table 4:** Economic valuation of bentonite clay powder reclamation investment

Investicija / Investment	255.000,00 €
Poraba komponent za livarski pesek pred investicijo / Consumption of foundry sand components before investment	395.614,29 €
Poraba komponent za livarski pesek po investiciji / Consumption of foundry sand components after investment	286.571,43 €
Letni prihranek komponent za livarski pesek / Foundry sand components savings	109.042,86 €
Prihranek pri odpadnem pesku / Scrap sand savings	21.857,14 €
Zmanjšanje deleža izmeta / Reduction in rejection rates	12.142,86 €
Skupni prihranek / Total savings	143.042,86 €
Skupni stroški delovanja regeneracije / Total reclamation operating costs	8.500,00 €
Dejanski prihranek / Actual savings	134.542,86 €
ROI (leta) / (years)	1,9

Pri celokupnem izmetu je t Stat absolutno $< t$ Critical two tail in je P two tail $> 0,5$, kar pomeni, da hipotezo sprejmemo. Med aritmetičnima sredinama celokupnega izmeta pred in po uvedbi regeneracije ni razlik. Enako lahko ugotovimo za izmet, viden po mehanski obdelavi. Čeprav ne moremo ugotoviti statistično značilnih razlik, vseeno vidimo manjše spremembe. Celokupni izmet se je spremenil za indeks 101,9, izmet po mehanski obdelavi pa za indeks 96,4.

4 Upravičenost investicije

Stroški investicije v regeneracijo se običajno povrnejo v dokaj kratkem času. Prihranki so pri materialih za pripravo peska, stroških priprave peska in odvozu na deponijo za odpadni pesek. V tabeli 4 so navedena vrednotenja stroškov in prihrankov uvedbe regeneracije bentonitnega peska.

5 Zaključek

Dodatek kremenčevega peska se je z uvedbo regeneracije zmanjšal za približno 40 %, proporcionalno sta se zmanjšala tudi dodatek bentonita in črnine.

Delež odpranih snovi se je zmanjšal, kar pozitivno vpliva na bentonitni pesek. Celokupne odprane snovi so se zmanjšale za slabe 3,7 %, anorganski del pa za 3,9 %. Na splošno lahko ugotovimo, da so se odprane snovi zmanjšale za slabe 4 %, kar pozitivno učinkuje na bentonitni pesek.

Delež drobnih frakcij kremenčevega peska $< 90 \mu\text{m}$, je ostal enak. Izračunane aritmetične sredine kažejo na rahlo zmanjšanje, za 2,2 %, kar pa ni statistično značilno. Kot pozitivno lahko vzamemo dejstvo, da se delež drobnih frakcij ni povečal. Pomembna razlika pred in po

Savings come from sand preparation materials and processes as well as transport of waste sand to landfills. Table 4 contains the valuation of costs and savings following the introduction of bentonite clay powder reclamation.

5 Conclusion

With the introduction of reclamation, the addition of silica sand was reduced by approx. 40%. In turn, bentonite clay and blacking proportions were also reduced.

The proportion of leached substances has decreased, which has a positive impact on bentonite clay powder. Total leached substances have decreased by just under 3.7% and inorganic substances by 3.9%. In general, it can be inferred that the total leached substances have decreased by 4%, which should beneficially affect bentonite clay sand.

The $<90\mu\text{m}$ fine silica sand fractions proportions were unaltered. Arithmetic mean calculations are indicative of a minor non-statistically significant 2.2% decrease. Also positive is the fact that the proportion of fine fractions has not increased. Another important difference before and after the introduction of sand reclamation is also the variability in the fine fraction proportions. Namely, after its introduction, the proportions were much more uniform (Figure 8) as a result of a 10-times small variance.

The rejection rate has remained unaltered, i.e. has remained as statistically significant as before the introduction of reclamation. Regardless, the arithmetic mean calculations have indicated minor changes. Meanwhile, the total rejection rate has increased from 5.2% to 5.3%, that is by 1.9%, the rejection rate following machining has decreased from 2.8% to 2.7%, which constitutes a 3.6% reduction which can

uvedbi regeneracije je tudi variabilnost deleža drobnih frakcij. Po uvedbi je ta delež mnogo bolj enakomeren (slika 8), saj je varianca približno desetkrat manjša.

Delež izmeta se ni spremenil, torej je ostal statistično značilno enak, kot pred uvedbo regeneracije. Kljub temu pa izračunane vrednosti aritmetičnih sredin kažejo na rahle spremembe. Med tem, ko se je delež celokupnega izmeta povečal s 5,2 % na 5,3% oziroma za 1,9 %, se je izmet po mehanski obdelavi zmanjšal z 2,8 % na 2,7 % oziroma za 3,6 %, kar lahko pripišemo učinku regeneracije. Po uvedbi regeneracije je nihanje deleža izmeta manjše, saj se je varianca zmanjšala z 0,55 na 0,32.

Izračun vračanja investicije nam pokaže, da se sredstva, vložena v regeneracijo, povrnejo v roku, krajšem od 2 let, kar je dokaj kratka doba vračanja.

Na splošno lahko sklenemo, da je z regeneracijo možno močno zmanjšati porabo peska, vplivati na parametre bentonitnega peska, ki povečujejo delež izmeta in zmanjšati variabilnost parametrov proizvodnega procesa.

Pomemben je tudi ekološki vidik, ki se mu tukaj nismo posebej posvetili, so pa zmanjšani odpadki vključeni v izračun ekonomske upravičenosti.

be attributed to the effects of reclamation. Following the introduction of reclamation, the rejection rate variation is smaller resulting in the decrease in variance from 0.55 to 0.32.

ROI calculations show that the reclamation investment should be recovered within the relatively short period of less than 2 years.

In general, it can be inferred that foundry sand consumption could be decreased significantly via the introduction of reclamation, and that the latter also impacts bentonite clay powder parameters that increase the rejection rates and reduce the variability of production process parameters.

Also important is the environmental aspect which is not the focus of this article. However, a reduction in waste has also been incorporated into economic feasibility calculations.

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