ENHANCEMENT OF COAL FLOTATION BY ULTRASOUND

ULTRASON YOLUYLA KÖMÜR FLOTASYONUNUN İYİLEŞTİRİLMESİ

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ABSTRACT: Ultrasonic treatment is widely used for surface cleaning during physical, chemical and physico-chemical processes in mineral processing. In this study, coal flotation with newly developed ultrasonically assisted flotation cells was investigated in detail. Representative hard coal slime samples from Prosper-Haniel Coal Preparation Plant located in Bottrop, Ruhr Region of Germany were used for this purpose. Ultrasonic flotation with variable frequency and power levels was carried out using Wemco type flotation machine with an impeller speed of 1200 rpm and 1.3 litre capacities. The reagent for coal flotation was Ekofol-440 with variable dosages during conventional and ultrasonic flotation experiments. The results of the release analyses showed that ultrasonic coal flotation yields more combustible recovery and lower ash values in concentrates than conventional flotation at similar reagent dosages.

Key Words: coal flotation, ultrasound, ultrasonic treatment, hard coal, coal slimes

ÖZ: Ultrasonik işlemler cevher hazırlamadaki fiziksel, kimyasal ve fizikokimyasal süreçler esnasında çoğunlukla yüzey temizleme için kullanılmaktadır. Bu çalışmada, yeni geliştirilen ultrasonik dalga üreteçli flotasyon selüllerinin kullanımıyla gerçekleştirilen kömür flotasyonu detaylı olarak araştırılmıştır. Bu amaçla, temsili taş kömürü şlam numuneleri Almanya, Ruhr Bölgesi'ndeki Prosper-Haniel Kömür Hazırlama Tesisi'nden temin edilerek kullanılmıştır. 1200 dev/dak pervane dönüş hızı ve 1,3 litre hacim kapasitesine sahip Wemco tipi flotasyon makinasının kullanıldığı ultrasonik donanımlı flotasyon deneyleri, değişken frekans ve güç seviyelerinde gerçekleştirilmiştir. Konvansiyonel ve ultrasonikli flotasyon denemelerinde kömür flotasyonu reaktifi olarak değişken oranlarda Ekofol-440 isimli ticari kimyasal kullanılmıştır. Release analiz sonuçları aynı miktarda reaktif kullanımıyla ultrasonikli kömür flotasyon deneylerinde konvansiyonel kömür flotasyonuna oranla daha yüksek yanabilir verimle ve daha düşük kül içerikli konsantreler elde edilebileğini göstermiştir.

Anahtar Kelimeler: kömür flotasyonu, ultrason, ultrasonik işlem, taş kömürü, kömür şlamları

INTRODUCTION

Froth flotation process can be influenced by a large number of material, chemical, equipment and operational variables. Changing one of these variables certainly affect the results of flotation, such as grade and recovery significantly. Ultrasound is one of the important treatment methods used to advance the flotation process, (Stoev et al., 1992; Ozkan, 2002).

Chemical effects of ultrasonic treatment in a flotation system are characterised by cavitation and are accompanied by a local increase in pressure and temperature. As solid/liquid interactions are weaker than liquid cohesion forces, solid/liquid interfaces are more amenable to the formation of cavitation. The unsettled conditions caused at a solid/liquid interface can modify the surface properties of minerals, leading to changes in the adsorption of collectors on minerals and accordingly in their flotation responses. However, dispersive effects are realised when ultrasound is applied to a pulp containing a stabiliser such as a surfactant; this phenomenon concludes with the formation of an emulsion. Ultrasonic treatment can improve the effectiveness of a reagent due to more uniform distribution in the suspension and also in enhancement of the activity of the chemicals used, (Jordan, 1991; Letmahe et al., 2002; Harrison et al., 2002; Mitome, 2003; Vargas-Hernández et al., 2003; Ozkan and Kuyumcu, 2005; Yu and Yalcin, 2005; Ozkan and Kuyumcu, 2006a-b).

In this study, hard coal flotation was optimized by conventional evaluation methods and the results were compared with ultrasonic flotation data in order to categorize the effects of ultrasonic waves on various phases of flotation.

MATERIAL AND METHOD

Hard coal slime samples in pulp form from the flotation feed section of Prosper-Haniel Coal Preparation Plant were provided by a coal mine situated in Bottrop, Ruhr Region of Germany. Coal preparation flow-sheet of Prosper-Haniel Plant is shown in Figure 1 in detail and the place (SAMPLING) where the current samples taken is illustrated on the figure, (Kuyumcu, 2004).

Original size distribution, calorific value, ash and sulphur contents of the slime samples on dry basis are given in Table 1.

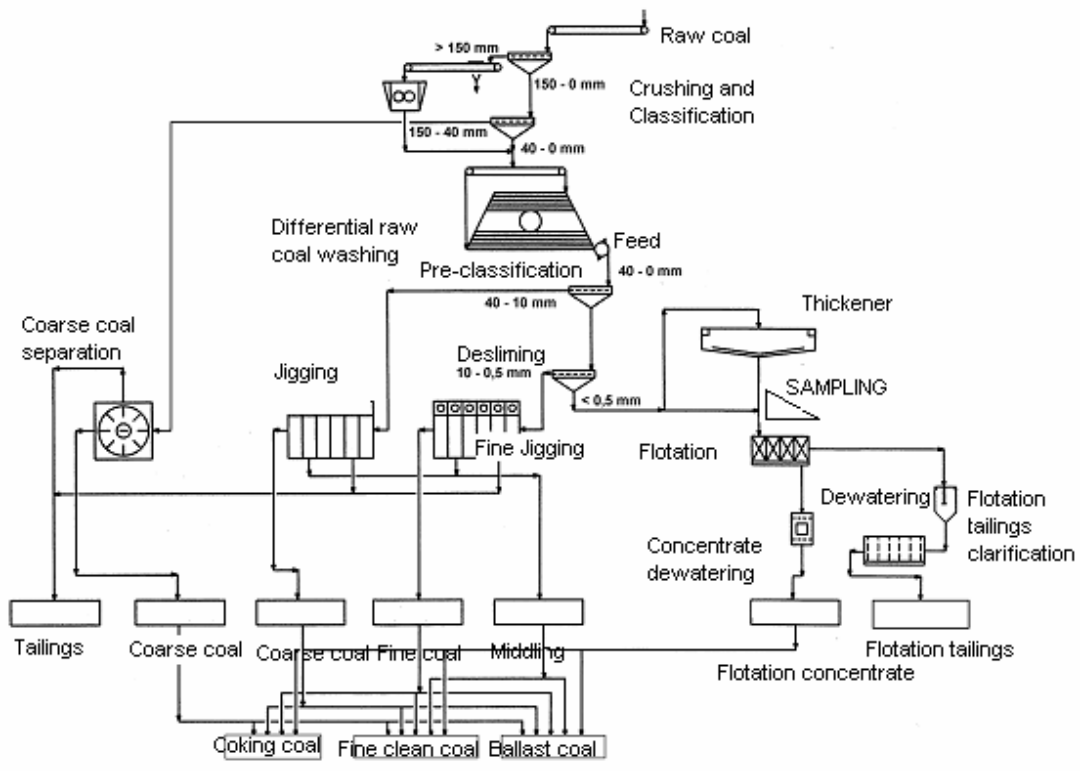

Figure 1: Flow-sheet of Prosper-Haniel Coal Preparation Plant
Şekil1: Prosper-Haniel Kömür Hazırlama Tesisi Akım Şeması

Table 1: Original Size Distribution, Calorific Value, Ash and Sulphur Contents of the Sample (Dry Basis)
Çizelge 1: Numunenin Orijinal Tane Boyut Dağılımı, Isıl Değeri, Kül ve Kükürt İçerikleri (Kuru Bazda)

Particle Size mm	Weight %	Ash %	Sulphur %	Calorific Value kJ/kg
> 0.500	3.20	2.12	0.84	34 136
0.500-0.315	9.89	5.10	0.90	33 286
0.315-0.250	5.94	13.41	0.86	30 311
0.250-0.100	17.32	20.73	0.87	27 259
0.100-0.050	9.82	29.21	0.93	23 708
0.050-0.025	8.90	28.71	1.04	23 666
< 0.025	44.93	57.57	1.19	12 721
Total (Feed)	**100.00**	**36.25**	**1.04**	**21 056**

Batch flotation tests were conducted with a Wemco type machine with an impeller speed of 1200 rpm. Ultrasonically assisted flotation tests were carried out using a newly designed and developed stainless steel flotation cells with a volume of 1.3 liters for each different frequency. The new flotation cells were equipped with ultrasound transducers with different frequency and power levels. A 600 W power generator was used with variable power levels. A schematic view of the newly developed ultrasonic flotation system cell is shown in Figure 2.

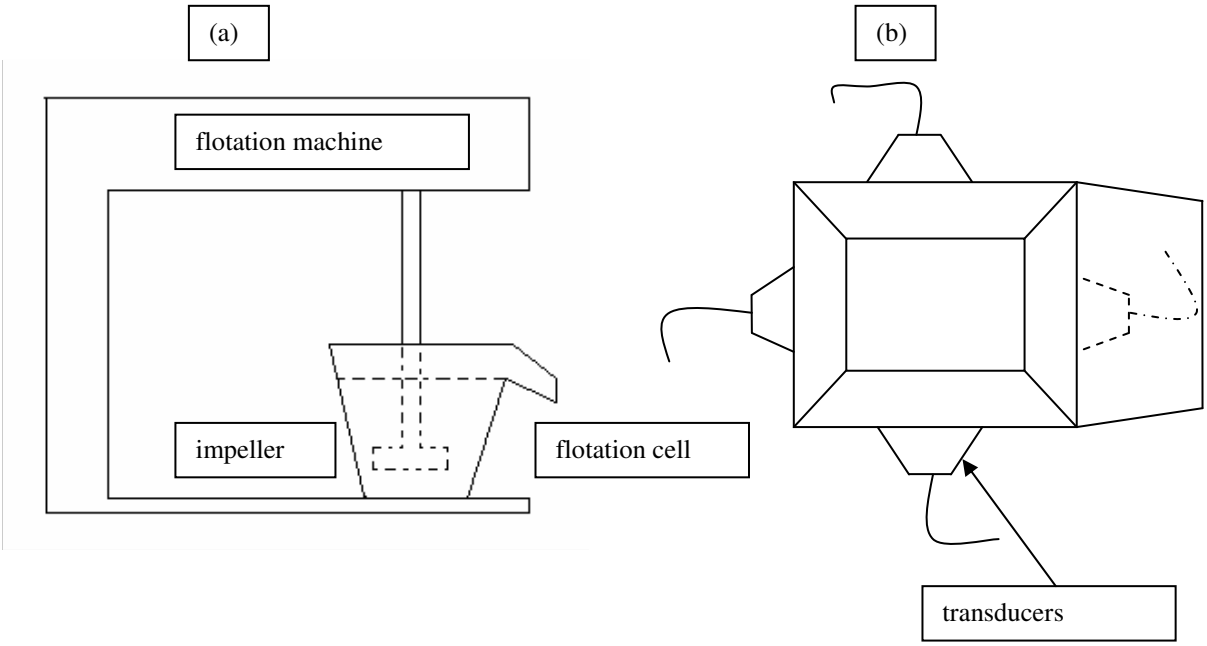

Figure 2: Technical Drawings of the Newly Developed Flotation Cells with Ultrasonic Transducers, (a) Schematic View of the Flotation Machine and Cell, (b) Close and Upper View of Newly Developed Flotation Cell with Ultrasonic Transducers

Şekil 2: Yeni Geliştirilen Ultrasonik Üreteçli Flotasyon Selüllerinin Teknik Çizimleri, (a) Flotasyon Makinası ve Selülünün Şematik Görünümü, (b) Yeni Geliştirilen Ultrasonik Üreteçli Flotasyon Selülünün Üstten ve Yakından Görünümü

The ultrasonic power generator, transducers and other related equipment were supplied from Bandelin Electronic GmbH&Co. KG in Berlin, Germany. Connection between flotation cells and the ultrasonic equipment was performed at the laboratories of Berlin Technical University. Ultrasonic transducers have a power capacity of 50 W with different dimensions for each frequency. Frequency levels were arranged for various batch flotation tests as 25, 40 and 25-40 kHz. Ultrasound generator was run at 50% of total output power during all stages of flotation, i.e. conditioning and aeration.

The provider of the ultrasonic equipment reported that the overall energy loss is approximately 10 % and the electro acoustic overall efficiency per cell is approximately 65 %. The losses are independent of the frequency. According to these assumptions, the unit ultrasonic power intensity was estimated to be 1.146 W/cm^2 for 40 kHz frequency, 0.801 W/cm^2 for 25 kHz frequency and 0.943 W/cm^2 for 25-40 kHz multiple frequencies. These data can be transformed to 60 Watt/litre for each flotation cell independent of the frequency.

During the bacth flotation experiments, Bottrop mine site local water as sample was in original pulp form with a solid-liquid ratio of 10 %, ambient temperature, natural pH, electrical conductivity and oxidation-reduction potential of the slurry. Flotation times were selected as 5 minutes for conditioning and aeration separately. Ekofol-440 was used as coal flotation reagent. This is commercially known as basically a combination of aliphatic alcohols in the C_6 to C_{10} range with free of phenols and phenol derivatives.

RESULTS

Experimental studies can be grouped according to conventional and ultrasonically assisted flotation tests using similar variable parameters for comparison and evaluation of the concentration results.

Release analyses (Laskowski, 2001) were performed for evaluation of the continuous flotation data obtained at optimal batch flotation parameters obtained from a previous study. According to release analyses, tailings can be evaluated either separately and collectively, however the products can be grouped in terms of different time intervals. Concentration tables were constructed to calculate cumulative and fractional batch flotation data. The calculated cumulative flotation data in terms of ash and combustible recovery values of floated products for comparison against variable ultrasonic frequencies were given in Figure 3.

The purpose of these tests is in order to demonstrate and to clarify the yield and combustible recovery differences between conventional and ultrasonic flotation tests by taking the ash content of each product into account.

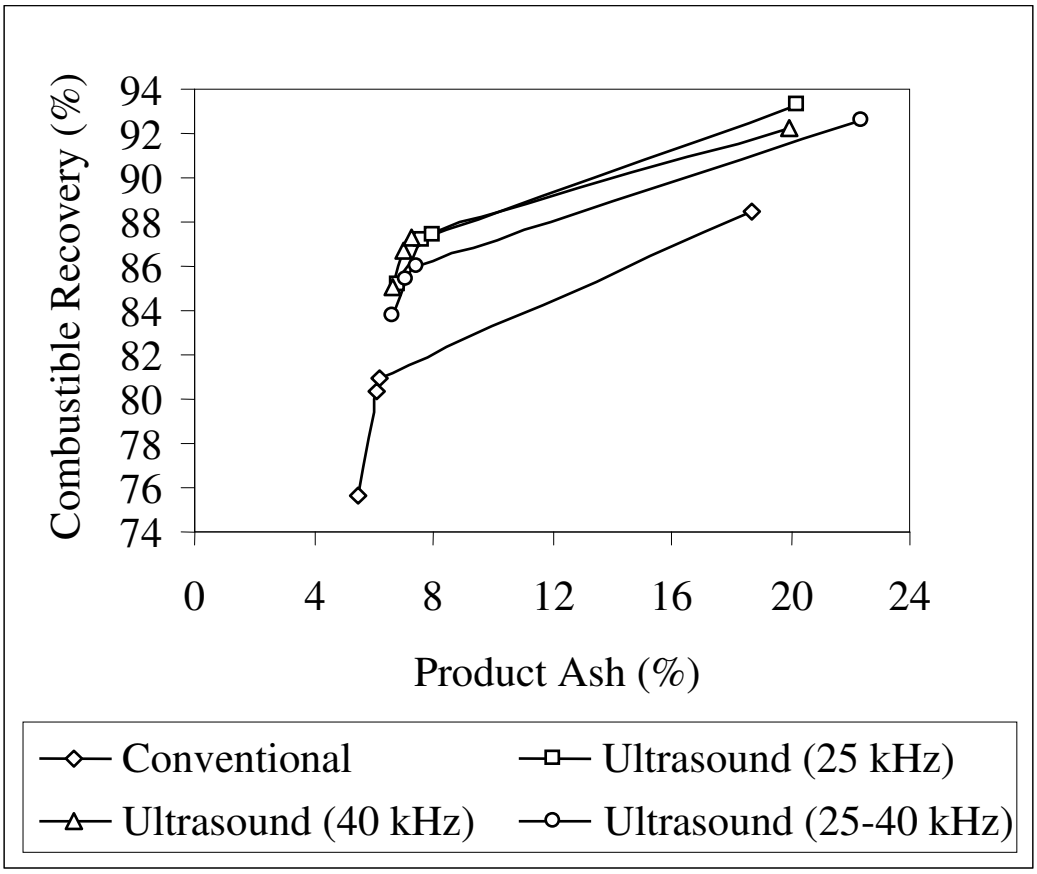

Figure 3: The Comparison of the Cumulative Product Ash Values against the Cumulative Combustible Recoveries at Different Ultrasonic Frequencies according to the Results of the Release Analyses Method

Şekil 3: Release Analiz Yöntemine Göre Farklı Ultrasonik Frekanslarda Kümülatif Olarak Yanabilir Verim ve Ürünlerin Kül İçeriklerinin Karşılaştırılması

From Figure 3, it seems that there is a similar positive trend between frequency change of ultrasound in terms of product ash and combustible recovery values. Therefore, the results of the release analyses certainly support more positive effect of ultrasonic treatment than in conventional flotation conditions.

DISCUSSION AND CONCLUSIONS

According to previous studies, ultrasonic flotation may be performed during the different stages of flotation, such as before flotation for conditioning only, or during flotation-aeration or after flotation for destruction of the coal and reagent loaded froths.

This study investigates the overall effect of ultrasound during every stage of flotation. A newly designed and equipped flotation cells were also introduced into coal flotation. This new system enables using ultrasonic power and frequency which could be easily controlled during the experiments.

Some of the positive observations can be outlined as;

- Conditioning and aeration, therefore total flotation times are certainly shortened,
- Froth or air bubble sizes are uniformly distributed inside the flotation cell and tend to become finer,
- Temperature certainly tend to increase by time, however coal flotation does not continue more than 5 min, therefore increase in temperature did not necessarily affect the results,
- Effect of breakage of the particle size of the products was observed, however it was not effective as it was previously thought,
- Reagent consumption drastically decreased by use of ultrasound due to thorough contact between collector-frother and coal particles,
- Although the quality of the floated coal seems to be not affected under ultrasonic treatment, tailings do not seem to contain coal particles, this may lead to improved recovery of coal flotation by ultrasound.

ACKNOWLEDGEMENTS

The author wishes to thank Prof.Dr.Ing. Halit Z. KUYUMCU of the Dept. of Mechanical Process Eng. & Solids Processing of Berlin Technical University, Germany and the Alexander von Humboldt Foundation for providing scholarship in order to carry out scientific research on use of ultrasound in flotation.

GENİŞ ÖZET

Son yıllarda yapılan araştırmalar göstermiştir ki, flotasyon işleminin farklı aşamaları bazı durumlarda mekanik titreşimler, ses dalgaları ve bu iki fiziksel davranışın ortak etkisiyle olumlu olarak etkilenebilmektedir. Cevher hazırlama-zenginleştirme ve üretim metalurjisindeki bazı ultrasonik işlem uygulamaları, akustik ortamların verimler üzerinde pozitif etkiler oluşturduğunu göstermektedir. Geçmişte yapılan çalışmaların büyük bir kısmında flotasyon reaktiflerinin emülsifiye edilmesi ve minerallerin adsorbe olmuş reaktif tabakalarından uzaklaştırılması gibi ultrasonun flotasyon öncesindeki etkisi üzerinde durulurken, son yıllardaki araştırmalarda ultrasonik işlemin flotasyon esnasındaki ve/veya sonrasındaki etkileri incelenmiştir. Genel olarak, ultrasonik titreşimlerin etkinliğinin minerallerin doğal yapıları ve ultrasonun uygulama yöntemine bağlı olduğu bulunmuştur.

Flotasyon prosesi işlem gören cevhere, işlemde kullanılan kimyasallara, işlemin uygulandığı tesise ve işletme koşullarına bağlı olarak çeşitli değişkenlerden etkilenebilir. Bu değişkenlerden sadece bir tanesinin değiştirilmesi flotasyonun başarısında, örneğin ürün kalitesi ve miktarı gibi çok etkin rol oynar. Ultrasonik işlemler günümüzde flotasyonu geliştirmek için önemli bir işlem olarak kabul edilmektedir. Bu etki kavitasyon ile oluşur ve ortamın basıncı ve sıcaklığının artması olaya eşlik eder. Kullanılan kimyasalların etkilerinin artırılmasının yanı sıra bu reaktiflerin flotasyon ortamında üniform bir halde yayılması da bu etkiyi destekler.

Bir flotasyon sisteminde ultrasonun davranış etkisi genellikle kavitasyonla nitelendirilir ve buna sıcaklık ve basınçtaki bölgesel artış eşlik eder. Katı-sıvı etkileşimleri sıvıyı bir arada tutan iç kuvvetlerden daha zayıf olduğu için, katı-sıvı arayüzeyleri kavitasyon oluşumuna daha yatkındır. Zayıf katı-sıvı etkileşimlerinde dahi ultrason yardımıyla bir flotasyon pülpünde hidrofobik taneler kolaylıkla oluşturulabilir, çünkü kavitasyon bu tip ara yüzeylerde daha etkindir. Ultrason flotasyon ortamındaki reaktiflerin daha homojen dağılımını temin ederek, etkinliklerini geliştirir ve ayrıca kullanılan kimyasalların daha aktif olarak sistemde yer almasını sağlar.

Bu çalışmada, yeni geliştirilen ultrasonik dalga üreteçli flotasyon selüllerinin kullanımıyla gerçekleştirilen kömür flotasyonu detaylı olarak araştırılmıştır. Bu amaçla, temsili taş kömürü şlam numuneleri Almanya, Ruhr Bölgesi'ndeki Prosper-Haniel Kömür Hazırlama Tesisi'nden temin edilerek kullanılmıştır. 1200 dev/dak pervane dönüş hızı ve 1,3 litre hacim kapasitesine sahip Wemco tipi flotasyon makinasının kullanıldığı ultrasonikli flotasyon deneyleri, değişken frekans ve güç seviyelerinde gerçekleştirilmiştir. Konvansiyonel ve ultrasonikli flotasyon denemelerinde kömür flotasyonu reaktifi olarak değişken oranlarda Ekofol-440 isimli ticari kimyasal kullanılmıştır. Sonuçlar göstermiştir ki, ultrasonikli kömür flotasyon deneylerinde konvansiyonel kömür flotasyonuna oranla daha yüksek yanabilir verimle ve daha düşük kül içerikli konsantreler aynı miktarda reaktif kullanımıyla elde edilebilmiştir.

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Yayına Geliş - *Received* : 26.10.2006
Yayına Kabul - *Accepted* : 16.03.2007