SOLIDIFICAREA REZIDUURILOR DE INCINERARE PRIN OMOGENIZAREA HIDRAULICĂ ÎN ŞLAM DENS

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REZUMAT. Prezentul articol descrie modul de concepere şi proiectare a unui mixer hidraulic la scară de laborator pentru obţinerea şlamului dens şi a rocii de cenuşa în scopuri de cercetare. La nivel mondial, procentul cel mai mare de energie electrică este produs în termocentralele pe cărbune (FCPP). În urma arderii cărbunelui rezultă o cantitate semnificativă de cenuşa şi zgură care în final sunt depozitate în haldă. De asemenea se procuce o cantitate semnificativă de subproduse rezultate de la staţia de tratare a gazelor de ardere (FGT), care la fel ajung în haldă. În anumite situaţii, cenuşa fină se poate utiliza în industria cimentului, iar subprodusele FGT ca material primar în constructii civile. Reutilizarea acestor produse depinde de compoziţia chimică elementară a cărbunelui şi de tehnologia FGT aplicată. Cu toate acestea doar o mică parte din producţia totală a acestor produse este refolosită, majoritatea cantităţii fiind depozitată în haldă. Una din metodele ecologice de depozitare a acestor tipuri de deşeuri în halda este cea a şlamului dens, prin care se realizeaza un amestec omogen între cenuşă şi apă, la anumite proporţii, cu scopul de a activa reacţiile chimice de cementare a elementelor de acest gen conţinute în cenuşă şi în produsele FGT. Produsul final al acestei tehnologii este roca de cenuşă care fixează şi previne levigarea substanţelor nocive conţinute în cenusa şi produsele FGT.

Cuvinte cheie: șlam dens, cenușă fină, mixer hidraulic.

ABSTRACT. Fired coal power plants (FCPP) are producing the major percent of the electrical energy worldwide. As a result of the coal incineration, a huge amount of fly ash and slag are produce that ends in landfill disposal. Also the by-products resulted from the flue gas treatment plant (FGT) are produce in significant quantities that also ends in the fly ash landfill disposal. In some particular cases, the fine fly ash is used in cement industry and the FGT by-products as basic material for civil construction products. The reuse of those products depends by the coal composition and the technology of FGT applied. Anyway just a small fraction of the overall production of fly ash, slag and FGT products are reuse, and the rest ends in landfill disposal sites. One of the environmentally friendly technologies of landfilling for this materials is dense slurry that create a homogenous mixture between incineration products and water in a controlled proportions with the aim to activate the cementing reactions of such chemical elements contain in fly ash and FGT products. The resulted product is the "ash rock" that encapsulate and prevent the leaching of the harmful elements contain in fly ash and FGT by-products. This paper presents the concept and how to design a laboratory hydraulic mixer in order to obtain dense slurry and ash rock for research purpose.

Keywords: dense slurry, fly ash, hydraulic mixer.

1. INTRODUCTION

The power plants that are running on fossil fuels, following a long history, remain today the main source of energy. Most common fossil fuel for power plants is coal. There are different types of coal, depending on the extraction site the chemical composition and the calorific value varies from case to case. However, the incineration processes of coal generate harmful emissions, with a significant impact on all aspects of life, ranging from individual health to global climate issues. One of the products arises from coal combustion is solids residues that can be summarized as follow:

− raw ash – collected from the economizer and air preheater areas of the steam boiler;

− fly ash – collected from the electrostatic precipitator and de-dusting ducts of the flue gas;

− bottom ash – provided from the burning chamber of the boiler that contains boiler ash and incombustible fraction of coal;

− air pollution control residues, reacted and unreacted that are accumulated from the Flue Gas Treatment plant (FGT).

The quantities vary from plant to plant as a function of coal type, applied technologies, age of the boiler, operational parameters, etc. Roughly estimating with 0.38 kg of raw coal produces 1 kWh electric power, 1.43 kg of raw coal equals to 1 kg of standard coal. Due to the lack of high quality coal and backward power generation technology, the combustion of 1 ton of coal will produce 250 kg to 300 kg of fly ash, and 20 kg to 30 kg of bottom ash.

The landfill disposal of fly ash constitutes a potential threat to environment through the leaching phenomenon and dust air pollution. [1]

Constituents depend upon the specific coal bed makeup, but may include one or more of the following elements or substances found in trace quantities (up to hundred ppm): arsenic, beryllium, boron, cadmium, chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium and vanadium along with dioxins and PAH (polycyclic aromatic hydrocarbon) compounds.

2. HYDRAULIC MIXING DEVICE

2.1. Chemical reaction background

Regarding the environmental issue produced by the land filling of the FCPP solid residues it was develop dense slurry technology (DST) which has proven its efficiency as environmental friendly, and so is already implemented at several FCPP worldwide.

DST presumes to create a homogenous mixture between solid residues arise from FCPP and water in a controlled proportions with aim to activate the cementing reactions of the elements contain in the ash. The final product of DST is the "ash rock" that encapsulate and prevent the leaching of the harmful elements contain in FCPP solid residues.

The cementing reactions develop in DST are strong influenced by [2]:

− intense mixing of the solid residues with a controlled quantity of water, which dissolving the calcium (CaO) and magnesium (MgO) oxides. The resulted solution partially enables the surface of the ash particles.

− the calcium hydroxide (CaOH) that has been formed is reacting with the minerals dissolved in slurry, and with the silicate dioxide (SiO_2) and aluminum oxide (Al_2O_3) having as a result the formation of the calcium hydrates and/or calcium aluminate known in the cementing process.

− the presence of the reducing substances as sulfates and sulphurs enable a lower value of the *p*H and the massive precipitation of calcium carbonate resulting the calcium and aluminum sulphate which is participate also to the cementing reaction of the dense slurry.

The main chemical reactions characteristic for cementing chemical process are:

− generation of calcium and sulfate ions (fast reactions) [3]:

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (1)$$

$$Ca^{2+} + SO_4^{2-} + 2H_2O \leftrightarrow CaSO_4 \cdot 2H_2O_{(s)} \quad (2)$$

− ash rock formation (at the begining is a fast reaction):

$$6Ca^{2+} + 3SO_4^{2-} + 2Al(OH)_3 + 31H_2O \leftrightarrow$$
$$\leftrightarrow 3CaO \cdot 3CaSO_4 \cdot Al_2O_3 \cdot 31H_2O_{(s)} + 6H^+ \quad (3)$$

− formation of calcium silicate hydrates (slow reaction):

$$xCa^{2+} + 2xOH^- + SiO_2 + nH_2O \rightarrow$$
$$\rightarrow Ca_xSiO_{2+x} \cdot (n+x)H_2O_{(s)} \quad (4)$$

On cementing process arise new undissolved minerals compounds. New formed mineral crystals are gradually deposited by joining to others particles in the slurry mass encompassing them. In landfilling deposit, the new formed compounds are solidified by cementation reactions, and so are created the "ash rock" that encapsulates the undisolved elements in slurry.

2.2. Design criteria

The core of DST is the hydraulic mixing device, where takes place the intense mixing of the solid residues and water. Basically the mixing device consists of vessel and two recirculating pumps. An industrial mixing device is depicted in picture below.

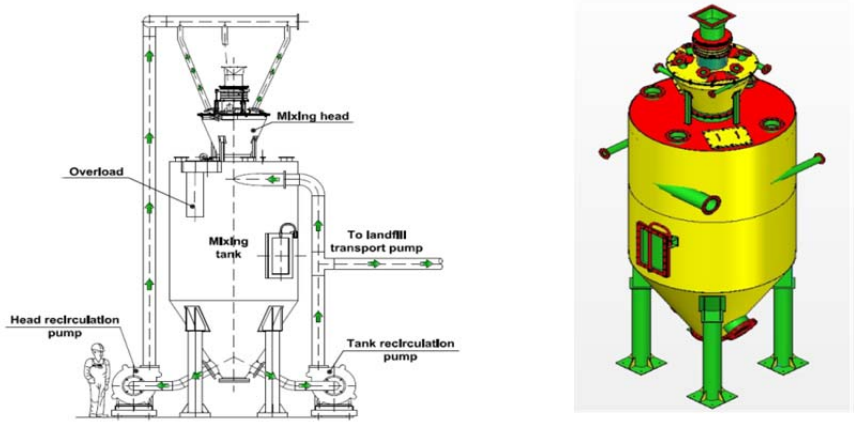
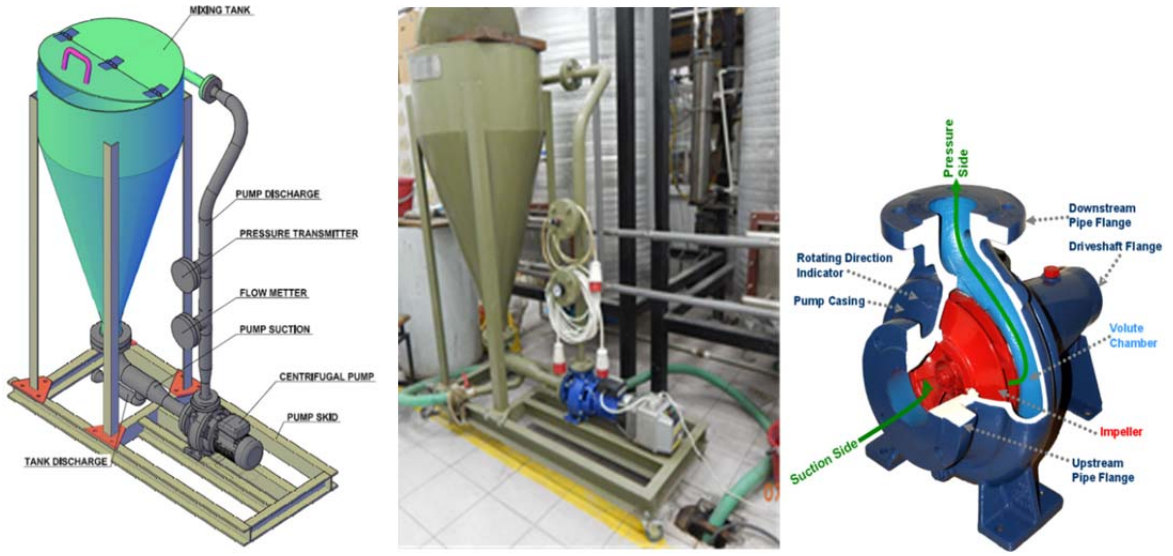


Fig.1. Industrial hydraulic mixer [2].



a. Hydraulic mixer design b. Hydraulic mixer manufactured c. Mixing pump

Fig. 2

Mixing process it develops in three phase as follow:

− in first phase take place the formation of the two phase mixture, between solid residues and water on the mixing head;

− on second phase the formed mixture is over mixed in the mixing tank, where the homogenisations occurs;

− the third phase takes place on the recirculating pumps, where is considered that the chemical reactions are kick started.

The most important phase is the third one where the pozzolanic elements contained in the fly ash are activated. The mineral structure of the fly ash is crushed by centrifugal driven force inducted by the impeller of the pump, and the water penetrates the mineral structure of fly ash and so the chemical reactions of cementing are activated.

Considering up mentioned phenomenon for a laboratory hydraulic mixing device, in order to create ash rock, it can be considered just the mixing tank and the recirculation pump. Figure 2.*a, b* illustrates the designed laboratory hydraulic mixer for dense slurry, from designing stages to the manufacturing:

In order to obtain the desired activation of chemical reaction, the selection of the pump plays an important role in design work. For this reason the centrifugal pump is recommended to mitigate following requests:

− pump casing volute type, made of cast iron or similar alloy steel, resistant to abrasion;

− closed impeller shape;

− drive shaft sealing resistant to abrasion;

− centrifugal speed around 1450 rpm.

A brief depiction of a suitable pump for dense slurry applications is depicted figure 2.*c*. For a proper functionality of the hydraulic mixer, it is necessary to maintain the mixture on continuously recirculation speed, otherwise the clogging occurs. The recirculation speed is influenced by the mixing ratio between solids particle and water, size of the particle and viscosity of the new formed fluid.

When high percentages of fined-sized solid particles (of less than 100 μm) are mixed with water, they usually form slurries, which do not behave like Newtonian fluids and in which the solids usually do not settle. There are various types of non-Newtonian fluids but in our case we deal only with a group known as Bingham fluids. A Bingham fluid could be described as a Newtonian fluid with an additional parameter, namely yield stress τ_0. This material behaves like a jelly when stationary and like a fluid when moving. [4]

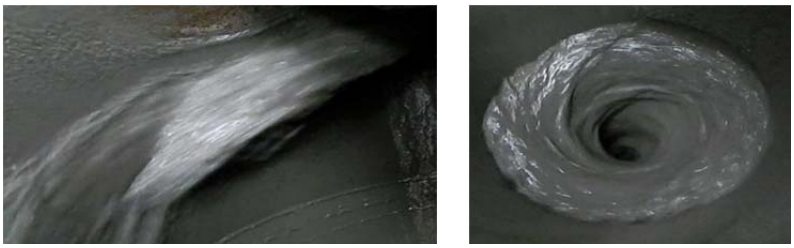
The flowing regime for these fluids has to be a turbulent one in order to avoid sedimentation of the solid particles. The flowing speed limit for slurries can be establish by using Durand or Wilson diagrams, or dedicated software that is able to handle this kind of fluids.

2.3. Designed size dimensions

In order to design a hydraulic mixer device for laboratory purpose, for our case we have establish that the reasonable volume for mixing tank should be 250 liters. For an efficient mixing process that occurs in the mixing tank is necessary to design a shape of the tank that during pump recirculation creates a vortex in the fluid mass which pass through the thank.

The optimal shape and design for mixing tank are depicted in figure 3; technical data of the laboratory hydraulic mixer are summarized in table 1.

For an easier operation and pump parameters controlling the hydraulic device was equipped with a frequency converter.



a. Discharge jet b. Slurry vortex

Fig. 4

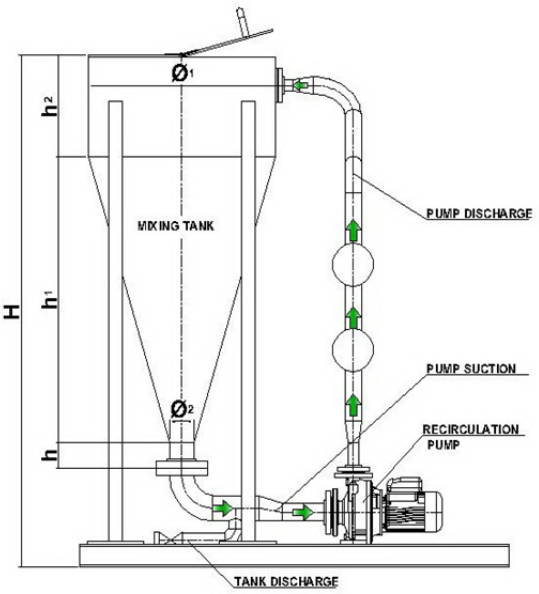


Fig. 3. Mixing device dimensions [m]:
$H = 1.79$; $h = 0.09$, $h_1 = 1.0$, $h_2 = 0.35$, $\phi_1 = 0.7$, $\phi_2 = 0.09$.

Table 1

Hydraulic mixer technical data

Mixing tank	
Usage volume	250 liters
Total volume	267 liters
Material	5 mm steel sheet
Recirculation pump	
Type	Centrifugal
Working fluid	Dirty water, slurries
NSPH	0.4 m
Working pressure	0.5 bar
Pump head	4.4 m
Impeller type	Closed shape
Impeller material	Stainless steel
Pump casing	Cast iron
Operation speed	1450 rpm

3. TESTING RESULTS

The designed laboratory hydraulic mixer device was tested with the different dense slurry mixture at mixing ratio solid particles/water ranging from 1:1.3 to 1:3. As solid particles were used fly ash and flue gas desulphurization products provided form FCPP CET Sud Timişoara. The predicted results of hydraulic mixer were accomplished with success. Figure 4 illustrates the formation of the fluid jet at pump discharge into mixing tank and the vortex in slurry mass.

From figure 4.a it can be observed that the discharge pipe into mixing tank is tangential to the upper cylindrical part of the mixing tank. This plays an important role for vortex stability during pumping recirculation depicted in figure 4.*b*.

4. CONCLUSIONS

The designed hydraulic mixer device is necessary in laboratory research work for dense slurry technology. With this device is possible to create different slurry mixture, by using reasonable quantities of materials. Minimum load of the hydraulic mixer is 30 liters.

Testing results provided by experimental work on the presented mixing device have been confirmed by industrial ones which validate the concept and designing applied on the presented hydraulic mixer.

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REFERENCES

[1] Wang Lan, Cui Yuansheng – *The application and development of fly ash in China*, World of Coal Ash (WOCA), May 7-10, 2007, Northern Kentucky, USA.

[2] E.G.I Contracting Engineering Ltd./Budapesta – *General feasibility study Timisoara Thermal Power Plant - Dense Slurry System*, 1999.

[3] Coaltech 2020 – *Evaluation of new and emerging mine water treatment technologies* – PART D, page 83, Available at: www.coaltech.co.za

[4] A.Grinza, A.Roundnev, K.E Burgess – *Weir slurry pumping manual first edition*, January 2002,Warman International Ltd.