CEER-PC-21

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?APROGRAM PROPOEAL TO

ESTABLISH THE FEASIBILITY OF

USING HIGH GRADIENT MAGNETIC SEPARATION,

FOR

EFFECTIVE TREATMENT OF MOSTOS

FROM PUERTO RICO'S RUM DISTILLERIES

DEPARTMENT OF PURE AND APPLIED PHYSICS

UNIVERSITY OF SALFORD

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CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

UNIVERSITY OF PUERTO RICO ~ U.S. DEPARTMENT OF ENEAGY

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PREFACE

The relatively recent technique of High Gradtent Magnetic

Separation (NGMS) 1s proving more and more to be a powerful, rapid

efficient and economical method for removing suspended matter from

water effluents of large volune with minigun requirement for

Process power and space

NGHS utilizes "state of art? technology and its applications

now include:

+ Mineral Processing

* Effluent and Waste-Nater Treatment

* chemical Processing

+ Biochemical Processing

* Pharmaceutical Processing

Organic waste waters all around the world have been shown to

be potent sources of water pollution of inmense dimensions. Various

organic waste waters that have been the subject of complicated

environmental investigations come from the manufacture of industrial

Products we use every day. Some examples are distillery and brewery

effluents, textile effluents, pulp and. paper effluent, tannery

effluents, pharmaceutical effluents.

Distillery waste water, for example, is highly charged with

organic matter and its treatment before dumping has recently been subject of intense investigations.

Although no hard evidence has been presented to prove that ?mostos' from run distilleries is harmful to human health or to the ecosystems where they are discharged, environmental authorities have decided that the associated discoloring of shorelines and nearby waters and the.nauseating odor of mostos make effective treatment mandatory in the shortest possible time.

Considerable work has been done on composition and treatment of distillery effluents. From the published results, however, it is apparent that none of the suggested treatment techniques has been found to resolve the problem satisfactorily.

On the basis that recent HGMS experiments at @ brewery in England have produced excellent results, we believe that HGMS will? prove to be a viable technique to solve mostos problems in Puerto Rico.

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The purpose of this proposal is to obtain funding for a program to investigate the applicability of HGMS to the specific mostos types produced in Puerto Rico.

The proposed effort would be carried jointly out by CEER/ UPR and"the Department. of Pure and Applied Physica of the Univer Hity'of Salford, near Manchester, England, a feader inthe. Field of HONS research and development. It includes a four month ex Perinental program at Salford. to obtain preliminary data, for ch Hws"Pitot Plane to treet mostos and the purchaser: insteltscion and operation of an experimental magnet a CEER/UPR for invest? ga-ting Focal samples?

The cost of the program is estimated at $90,000 over a Period of 12 months beginning June 1, 1978, and ending May 31, 1979. . Progress reports will be issued at least every four months and a final report will be issued not later than June 15, 1979.

The project would constitute a valuable addition to CEER's environnental program and an excellent vehicle for the training of environmental specialists and other scientific and technical personnel.

1.0 Principles of HGMS

A high gradient, high field magnetic separator (HGHS) consists of a ferromagnetic wire wool matrix, of strand radius a, which is magnetized to the saturation field M, by a uniform applied magnetic field. - Particles of radius R and®magnetic volume Susceptibility x can be extracted from a fluid, of viscosity 9. which carries the particles into the separator with a velocity V,. It has been found that a quantity Vj, called the magnetic velocity, is of great importance in the"determination of the performance of these separators. V, is given by

Von = § (xR*MietHo) mo

These separators have found application in the kaolin industry in the United States, in England and in Czechoslovakia. The Separators have a matrix bed depth of about 20 in. with a channel diameter of 84 in. The applied magnetic field is produced by passing a OC current through water cooled copper coils, weighing _ about 50-60 tons, which are wound solenoidally around the matrix channel. The power required to maintain the field is between 400-GQO_KW. The magnetic return circuit is in the form of an iron box weighing approximately 200 tons. Although the impure kaolin parti~ cles to be extracted are only weakly magnetic and of colloidal size, it is still possfble to pass about 1000 gall/min through the Separator and obtain adequate beneficiation.

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Although not yet in commercial practice, 1t has been found that organic mitertal, coliform bacteria, viruses, suspended solids and other colored matter, can be scavenged onto freshly. precipitated Feloh), or Feody. ?This 1s an electric charge effect thet wil be described in Aofe detail in section 2. The scavenged material can be renoved by extracting the Fe(O#), or Fesdy particles with & magnetic separator. This can be doke at high velocity because of the favorable magnetic properties of the seed material. This method is cumbersome to apply in practice and suffers trom the disedvan= tage that Pes* fons are added to the syste in solution.

However, a large British chemical company has developed a scavenging material that can be used over a wide range of pH and which simply requires the addition of these particles with an in line mixer. It is this method that we propose to use in the treat ment of mostos.

In section 2 we present an outline of the theory so that the main experimental data required for the pilot plant configuration and parameters will be apparent. In section 3, we outline the experimental program.

2.0 The Theory of Magnetic Separation

The equations of motion of @ diamagnetic or paramagnetic particle moving with a viscous fluid in the neighborhood of a magnetized wire have been derived and solved. Thus, it is possible to show that only certain wire configurations are effective in cepturing particles. Generally speaking, the? velocity of the fluid can be at any angle to the axis of the wire; however, the magnetic field component perpendicular to the axis of the wire is the only component of field which is effective in the capturing process. In this section we will focus our attention on the case in which the magnetic field and the flow will be parallel to each other with both being perpendicular to the axis of the wire. (Reference 1).

From the equations of motion, it is clear the particle tra~ Jectories depend almost entirely on V,/Vo, that is on the ratio of the magnetic velocity V, defined by ?Eqfation (1), to the velocity Vo of the fluid relative to the matrix. Consequently, the capture cfoss-section area/unit length of wire is 2Rea, where Re is, termed the capture radius which depends largely on & function of Va/Vq- A reasonable approximation for Re when Va/Vor2 is

Ry = 05 (Vp, /Vy) + KV @

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Here T 1s the residence tine given by eoL/Vo and A is 2 constant

of Such a value thet when ny the number of Canister volumes passed,

is n= 0, then Equation (3) and Equation (4) are identical.

At this point the criteria for effluent levels that are to

be used must be specified. Suppose that the final particle level

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linen n* has been determined, the total process rate P can be deter-

mined by

PeVA ©

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Here D is the dead time of the separator, that is the total time

the aparator 18 off during the cyclical ?cleaning process. (Refer-

ence 4)

Seeding and Scavenging Process

In a stable colloid, the particles have surface charges which have the effect of Keeping the particles apart or dispersed, Elecy trical potential barriers are normally greater. than = 15 tT where kp ts the Boltzmann constant and Yo is the teaperatufe: in degrees Keivine If particles are introdiced which have an opposite Surface charge there cen be a strong attractive force between the eppositely charged particles so thet if the potential difference

is) < 15 kgtg coagulation occurs. It is found that at normal pi, bacteria, cBifs, proteins, viruses and cell debris have a negative Surface charge and can be scavenged by the addition of a material With positive surface charge. As noted tn Section Ta large chea- eal Company. in England has developed « seed material which has 8 Strong positive surface charge over wide range. of pl velues. These are treated particles of Feg04 and are consequently strongly egnetic so. they can be effectively removed by the separator. The important element ts the volume of seed necessary to scavenge the organic material most effectively.

The proposed experimental program is based on an evaluation of the above scavenging method. The effectiveness of the seed and of organic removal will be tested using the theory laid out in this section.

3.0? Experimental Program

Microscopic Examination of Coagulation .

Using phase contrast microscopy an attempt will be made to exemine the interaction between the seed and the mostos. This can

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be done by the preparation of slides which are frozen in such a way that Seed material can be placed adjacent to the mostos on a microscope slide. The slide is then warmed so that the resulting interaction can be observed when thawing occurs. This part of

the program will attempt to look at mostos-seed kinetics and more particularly seed to mostos concentration ratios and also the

Seed to organic ratio in the coagulate so that Vm can be determined. Video recordings will be made if possible. Time spare for this part of the program is 6 man weeks.

Magnetic Separation Study

For this study it is proposed that only one matrix be used to save time. This matrix will be an ordered knitted mesh of 50 microns diameter of ferromagnetic stainless steel occupying about S% of space. The saturation magnetization is around 1.7.

It is also proposed that two magnetic fields, namely 1T and 2T, be used.

Based on the solids content of the mostos, various ratios of mostos solids volume to seed volume will be used ranging from 5 to land 1 to 1, respectively. .

For each of the above combinations it will be necessary to do experiments at various values of Vm/Vo. In practice this will mean holding No and seed dose rate constant and running at various values of Vo.

In each case, starting with a clean separator, the output will be monitored in order to determine the effluent concentration versus the number of canister volumes passed. This will allow n' the required number of canister volumes for a various effluent criterion RL, to be determined. Also, by running the separator until it is completely ineffective, the value of Ny can be deter- mired. The estimated time for this part of the program ts 16 man weeks:

The assembly of the results and the plotting of graphs will tabe approximately 2 man weeks.

The total time for the experimental program at the University

GL Sglfordwill be 36 man weeks to be accomplished during July -

ctober, 1978.

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MILESTONE CHART FOR MAGNETIC SEPARATION STUDIES

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BUDGET REQUIREMENTS FOR MAGNETIC SEPARATION PROGRAM

Direct Salaries plus Overhead $ 42,000

Includes

Principal Investigator (50), 1 year

Technician (50%), 1 year

. Consultants

University of Salford $ 14,000

Rose Magnetic Separation Consultant $ 5,000

$ 19,000

Travel

4 man trips $ 4,000

San Juan - Salford

Subsistence $ 2,000

$500/man trip

$ 6,000

Equipment

Test Magnet plus ?Assoctated $ 23,000

Equipment

Subtotal Estimated Cost $ 90,000

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SUPPLEMENTARY HGMS LITERATURE

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The Use of Paramagnelic Mairices for

Magnelic Separations?

By P. W. Riley and J. H. P. Wateon

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magnetic fields

JH. P. Watson

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Conclusion

Magic separators using upertonducting magnets hve

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References

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eprint ©1978 by Teas of Ec an Becton Eat, ae,

?ted MUSA. Anae. saa

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?ion efficitney for the nleerial pons thnrge he

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Gate Coe Pelee, Fak PN Te a, OD)

5: 50: Stay, oh, ethanol

2 gene Haden Hisuee

HE ES TE

"rats Mina. Brocess. Gong, Caeliert, Anrid, (1975).

---Page Break---

Seeding Principles of

High Gradient

Magnetic Separation

Christopher de Latour

reese sa ?Sor Maased tat Sanaa

This aril, tho second of x three-part sere

the precipitation ofA), Fett, Gut)

recipes, attr tne alton

?Te dscusion hat fellows andthe daa presented are based

4 prvi laboratory batch ter progr ha explored pec

?ion and congulation as they ser GMS. Thereore, Chores

River weer was abundoned sn favor of arial sampler, of sed water with known additives The held and ow paeome

{eria wells the chemical concentrations ured ae not ages

?he opdonm parnmetes for commercial spplstion of HOM

August 1976

Precipit

fon on a Magnetite Seed

Precpitate adsorption onto Fe,0, was achieved experientally

ty exeeding the solubily iit ofthe Sonn question i te

pretence of the dopesed magnetite. Immediately wpon addon

?ofthe fone species to the Sltion, ionic hydrops prc are

Tamed which havea xr, pov or aepawe chugs, depending arity on the fon concentration, the pH, ad te pence of

Ether completing ions. Thee ree for emerge crite

Precipitation proce and will uiimaely afc the formation

nes and the nae of he pea

The instantancoushydls peis are shotlve, because

te sion aad rps me ae

?reptte. The yerajis speces must change coordintion

{oeps through condensation reaction while evelving toward

sion prin tho prov dfn

thechargecf the hyrayi pecs For expe yea fos

ie fon FOl) ele met sale pean poop

Secen the species Fe(OH, (lb) requoer mo forbee

Condensation t become # hydaed frie Bydrxide pec

?Ubimatty, colodal hyroxo polyenes emerge which are

?netic intermediates inthe precipttion. sat hs sape that he

volving precpiats can begin zrpion onto the slit preset

it the Solution. These colbidal marae thescves have 80

furnceehuge nt some nig pi vase, cle te sero pln at

sags (2PC). Above (elon) ths ZPC. the collet spect have

2 seatve (postive) stice charge. Toe transom the

Colca! polymer tothe vse prspate depends srongl ot

the saree charge ad therfore he slvtion pl For vot text

the ZPC formato spi, brother pH vals rac charge

?eplins ctr the precipitation pron

During tis evolution. he magacite sod wrice act as an

ctorton it for the precipita chsh wil be removed wih he

feed in the magnet tepaioe Fires. 2 and 9 show the

Femoval by the magnetite ced of ete hyonde (ZFC = 70 19

42)¢ aluminum hydroxide (2PC = 6010 BO and cup onde

---Page Break---

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on or ke tae 0 3 en

ZAC = 95," In cach ease, the mont ficient prepa removal

?cess np interval around the ZFC

Note in Fig. 1 the stong dependence on te Fe(l) content.

oc $4 mg/L th istatantous hydrlys spei ht domiate

eveen ap of ¢and Gave ofthe frm Fe(OH

{6 OH ions must be removed ftom the Fe(i coord

pations, wich renrés pid preipston. Near a pH of 4

ower, Fe(OH), (oldie is he dominan hyéras specie

?tic ven apd loemaion and peri beter removals in

Fig. The prepa Knees improve a the conten of the

Feil) ion incense i more prespatin tome owes the

Feit emoval fig stloweation contents wil epprnch tat

©f21 6 pt Alisa can prespiaon shor neat

?These tune opine sce the mage was present when

he precipaion wat iniated. If he sect ade hie eipaton fa pope, the aging pres

?Morpive ete enema, lly fred nd

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rt for atachnat to the mage

CoPreciptations

?The uihforward precipiation ofthe hydroxide ox onde of

anion furbe conplested bythe presence of competing fot,

?hich in sunt gente wl fre the domain of net

?The close coeatin between Fe) and

?lor emoval of Fig implies thal the fre haat pepe

Increasingly dominses ver ei byron.

?second important coprecipitation i given Fig, S when the

cthophcphne ion preset ss compli spec. As the

$o, "conet incense, the fre phorphte patie domiane If

{be puricaon jee isto remove he othophorphate specie,

?cafeful selection ofthe csgatnt chem wed wil nah the

recipintion pono he stral pH of the water sample Ia Fg 6

the PO.? penton ir achieved in two dite 9 neous

?ing Fe and AU

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tine, Without be te of he magnetic teat vech pecpeations

ld regure op tan ender of magne more inet yell

?erable sais. The magnetic seed very cey an eccle

Caller of aqueous presi produce

Solids Removal

Fg 7 Sele Remora! by FO, vmoutCosgulntCaton

(nent NMC, she aie ah Eo HOM.

8 Sos Removal by FO, With Countct Caton

Fg Agee Remon va Fa, HOM Tresnent

soa eines neha ete

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ragpatic to sow rp removal in the separ. Asoo end

?Fecve bond beeen he apace nd he noniagaec ds

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"2, Dovble ayer compresion, because ofan incre i the

tonic coment fhe slotion, wl ete he parle insets to

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?apstit dove, the sluion pH and the ming tine before

Sepuraion® Conga vied "oday inthe proce of et

?weaiment cde alm, salem sluminne, ie and ferrous

soln, ind alge vay of organic payee sve

?Organic pajeaione ne add to ad ongenicn, whereas be

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{alutnn devoid of cogslant Subsegvent apne

Indicate the entent fe atocaion sole ey eure

?haigeteractons The ZAC valor of he mae ee ALO,

91-53 (i TO, 67 pH, SiO, 2 pH: and kaon cay 6 pt

?The ZFC for magnets aprosimaely 5 p>

?These epred values are connet with he wend of Fig. 7

?convde? for example he Incracn of IO. eed ogni

Mapeete sree charge aes fom pstve to nepureat he

PC of 63 at wich point the asain wih sen wep

tue ie tere of 2) son bin day The

?ame w ohurved forte hols-mapneie sytem, Ar teoer

?rampl AIO, sis ae postive on apponimately 91, Sedvorcplion expec onl the Pepe nea eas

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When a conplant i added tothe sto, the esa

?athe paniculata her hi surface charge characte.

?Alesis should therfore behove slaty he resem of

? coopulsnt Figure Sahows he mmc enpernent of Fi erp

forthe ws of 34 mgt Fell) and Smit AI), The 2M ot

lporance snow tat of the enagslant recipe wich wat

eued eater Fl} an AI} removes nay

Simtianeous sls separation mig 8 9 i daly the

[dec a the csgsan cauon tat ead to eemeshnet the

?operte andthe noemapeetic ode

?euble Lae Comprenton. Cangant ar nt alaye nee sary for ngzrezation.h Sapesion called or ner cos Dates assured if eerasate repli Sonne he ner sion. A sofia ices the eecocige cota the ?olen however, wl ease a severe compresin of he ai ing elecie dove lujer around each parte: Aocsaion il rel." This mechart nt wally emporio the procee SF wate purication, bo i important in ungetanding the beavior of particles in some natural suroweding for ?ample in esustine waters Doobe nye comprestor cxpans ?eres of xpinen ng NOMS fre ep ht

?When magaeite ie iapened in an ccanwatr sample, the gh nem eno ects tes sgrepnes rapicly Tamm asosining ie FeO, mith athe ?onmapneic preset ria Fig 9. Concenated sok samen of ?Gesent shaped Mucha. Roran cell (MING) nnd peal Chior lgn were ased% and experiments with the ee dense MNC exhibited beter emoval inthe hat ester iat Ot 1 phelomieroprph showng 4 Roc cher tha rut hee ?nape i led to seperate a slry of the two iret cl Flow rate during HOMS for hie alga elhrmoal ata wae § ?emis (1 gpmag fi, maling HOM very een meas for ?evening tater ais ae re rae pent eT

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Theory of Hi ent a Separation

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uation Suits Conlerarca on FlvaonFreducty and Pais

?ite, Sepuamae $9:28, 1893. ee Landes

Applications of and Improvements in

High Gradient Magnetic Separation

By JH. P. Watson

?Magnetic separation has been in we for many yer

in the mineral processing indosty for the remnat ot

?epuration of minerals In order '@ produce tis spas:

{fon hoth magnetic held and eld grin ure ncceeary

?The magncie eld has commonly becn produced fy

elecromgnets using iron in the magnetic Crit so that

the eld was limited to about 21 Fei graven

?tually produced by shaping or by tac" of sc"onsry

oles The material was ether held onto the secondary

Bole or deflected mechanically to achive separation

?These machines are well whe the particle sir I Teepe

and the materials are strongly magnetic. It is not

Possible to. separate colloidal spsems? with ?these

?Within the tas fw yeas high intensity snagaetic

separators (HIMS) or high wradlent nage sopetuons

GHGMS) have been developed tat alow weakly pare,

magnetic coloidal prices fo be extracted from Rand

?mowing through the seperator () These sstoms were

developed by the kaolin industry inthe United States)

tn co-operation with the France Biter National Magnet

Tabet

igh gradient magnetic separators, in practic, consist

of feromagaetic wire wool matt Secupying $105 of

Shace magnetized by 2 uniform magnetic ld 40 tht

Mogretie eid gradients? high at'T klogaus/nion

ar be achieved. ?The matrix tr sually helm constr

fino which the slurry ts Ted. paris are captured

?he ability of the mai to extract pails reduced.

?At any point the fiter con be cleandd by fst semoving

the magnetic iekt and then Mashing the: matrix. wilh

wale which cally "removes the captured mater

Keiviig" clean matrix When the tagnetic Bel it

?estore the magnete separation coa beg agin, Fig

sows a small hgh gradient magnetic separator bul by

Iutereaional Research and Development Co, Lid. of

NewcastleuponsTyae and. Fig. 2 tows the interal

rangement and the external plumbing for a typical

?GNIS system ofthe type in tae in the kala inet.

seth helt indy a te only comer

"pplication af tis technology which uses lero magaets

AUST. However, because of is ability to Tapily recess

?Stems, in comparison to other technologies,

ine of applications in mineral procesing. ih

waist and waste treatment, chemizal and biochemical

gineering and in pollution contol have been suggested

tnd have been he sehect of various experimen sedis

?These ave various ways the high radical magnetic

separators can be uted,

I. When there exis a dferene in magnetic suscepi-

bitty between two paramagnetic minerals they ean be

ifretialy"sepaated even though they? are of

fellodal ie

3 When the particles to be collected ae diamagnetic

ihey can be epurated by scavenging or conguating

?them with «paramagnetic material which can then be

Femoved with the separator.

Gitar

---Page Break---

3. When a dissolve species cum be precipitated on to

a magaetc carrer of mapnetic sell Hea be

?enoved by the para

?Tie purpoe of tht paper fist to sive a brie review

of se ofthe applications of high gration! mognelc

epuvation, secondly, 10 ouline the theory ef magnetic

?cparators and third, to show how by wring the theory

Sgniicant impeovements ofthe technology have beck

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field of 21 kilogaust) applied paralel to the sarey

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Research has been carried out by Kelland) at the

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Reus cena tet easy

removal of ligne and ash from solventsehned. euch

Sree ereten

ene coi Garena

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Cae cons cas rt spate a

HONS in the ste! making process. One ane of sce!

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ae

ace tiger Sam okt shah

Bair, beta ea oo

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Ge aril planes frac

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Beene ae ret ee

eo ee ee sere

inthe treatment of sewage ether in the present form ss

?currently exit with thecacivated elude tanks OF i

Stier newer methods that are being considered

(sludge tank, bacteria digest the nutelent and large flocs which grow i sie To» stage where they

ist

sel. ?The introduction af FeO sed atthe ac

?Sparalion ean be cnormounlyspcsded as sna

?in be handled and rapily heres ?This pres

normous reduction in acting tank spac.? Fina,

the'bter ssc poh

?beteria and spend

Wer wing Fes sced ma

Fiver i Roston has bec treated in tha way? On the st

Pass sewape sampler ave been trough to. prseal

{Eka vive standards as fr as coliform bacteria arb

Aily. clove and suspend sls are concerned On

fukcguont poss the water i adequste or Ginking

Inspd by tn tc clo, olay

tnd suspended sot")

ichat aso been found tat a retonale mount of

suspended sis are preset he ation AIS" sonst

the seution. wl remove? orthophorpate ions fom

{olution and ind them ino the Constant for removal

fn the separator?. if not enough supended sds are

present, the separation is aided bythe ation of tls

Fentonie iy? Orthophosphste fone from domestic

Ip en rou ot olan

ater efluem containing TOs Parties is & har

pallu in the ?American, Great Lakes-and? hr the

Medierancan. However, in certain pH ranges Iti

posible to produce cosgulaign between TOs and

fapncite i the pesene of Alo" and tit may tad

theremoval eft problem with HOMSC) Therap

removal of sbexon() and veal mateals from dino

?ater have alo been reported.? Much of the work of

Yast water treatnent had been reviewed by Oder and

ross tha henry meta i fi

Protest tht removes heany metal impure fom

was waters fr by product of proses 10 make ere

By mination Th ha tan said

?Nippon Elect Company and nthe proces

Gu, NivSn, Bo, Cr, Fe and Hp were reduced Tom the

level of gmaft down to 01 maf While much of the

Gi

?Another process that has been investigated at Univer

sig Col! Cand he we of maa ati

Supports i immobiled eneyme reactor?) pom

bie sing the large surface areas valable on Sra

parle to produce fax reactions without ong

IRedia, "The advantage of sold parties i tat the

Separation rom the Higuor is ckan and the active

tat ot ue The eo al para ne

tats the wae o is techie appears fo have

?ery wide posses, especial in bschemal enginger

Ing andi the pharmaceutical Induty.

{GMS technology has bern ued experimentally for

the separation of red cals from whole ood" and the fecovary of respirable asbestos Res from dust hasbeen

\eseribed by Timbre?) as prt oft method to estimate

See eek a

TT uy mapa

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Te ian ae Pa

Theory

?A theory of capture of paramagnetic particles has

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A Screen eee 8

Siaafrane eat) oot

Sigg eee eh ae eh

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ei tae ie a

improving productivity, lowering costs

now appropriate to consider features that are

esirable in a separator in Order to give 4 Tow cost)

roaased unit

Tigh duty ete

Z High production rate with high benefcstion.

3 Adegdate time to clean the mattcinalow magnetic.

fa

4. Low power requirements,

5 Cow capita cost

6 Simple maintenance and ooeation.

Many ofthese conditions are interinked so that in ?order th Understand the proces iis worth examining {he conventional HGMS that. fpicallyoperatr in the ?lay industry using a magnetic Rela of 21. For far?matrix material and for a parevar materia to be proces andi the system operates at 27; then the ot! one the weight

"hoped an hs

eae Then i the prouct

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Epon 6 ol manin he

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Systen his leas 10.4 high capital cost aad the mar

trust be leaned tthe end ofeacheyee whieh can olen

(Gado very low duty eye or an inadeguste time for

?AS oalined above, the extaction of materi by

separator depends lsrgely on Vale and the amount of

rl fe the Hopton At shown howe the

?rodvetion rate of such « machine & roughy propor:

oma tal extation of mater & Foy

Proportional te 1/Vo. Thi menns tha inorder ta" get

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Some vue, ay a. In order to lneese te prodstion

Fic, Vo must be increased and itis to be done with

Fut lowering the eataeion, Vu. mist be insredsed 20

the Wa: ay th oe one oe the

igh atagetic eld tht superconducting mapreties can

Iovide to incresse Vow ?Another way tha this coh Be

Aloe 1 alow the frromapncie mars to move tobe

Stanly with he fT hd moves slowly Sowne

ward pon the wire witha small eave velocity Vo but

Hass high forward speed Ve hentia! that ofthe wie

Under thse cons th extraction i determined Sy

fb. bt the production fate it rrughly proportion

1SVench canbe made targa wet say

teociy i Ve the foal length of

Kast L'-WVir- Once out of the Feld the wires can easily

fe washed. Vi can be made?

order to make VaVoee only a small value

£2Vp it ceded and this can be Considerably sa

VaraaVe The requirement of larger value of Vinca

erefore be relaad so that & ow vue of applied eld

?ean be used. Im practic this Held can be at

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"These two methods are discused in the next two

sections and both have disunet advantages over the

peesent HOMS stem operating near 20 KG.

igi epee ene

Le tc, ohn

neti chet tt

fo cetrical reastance The resistance can be restored

iegireememane rea ers

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fesistaneeIn-a commercial sytem iqud helium would

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Fiosen at 77K although in 3 commercial machine ths

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?Expcrimenul work with a superconduesing séparator

tas confirmed thatthe erfgrmance of piven separator

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Drodeetion rate ean Be ncreased due fo the fac thot Ve

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Soubie canister system.?"One canister is inthe held

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Edniter ean now be cleaned gut ofthe Bld und te much

times the Ferd and nse time can be then. tn practice

the conventional HOMS tytem has a detd tine D of

berwven 100-200 sec whereas the canister replacement

can wanly be accomplished within 10 see. ?These two

Fis lead to appreciable diferences in the production rate Py of « superconducting machine rclatve 10 the

fate Fol a conventional machine of the sume matic

Snir dimension

Tn order to ilstat thet factors the relative prodoc-

tion rate PP, venus ty is shown in Fig. 5. These

urn atecaleuited for'a dead ime of I se forthe

Superconducting system and of 100 and 20 Sec forthe

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Fig. the relative production is ?reater than 9 ven

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?Another important factor is the electrical power

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400-608 LW 0 thi the power consumption also ges

the superconducting system consserable wdvantages:

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The overall configuration of this separator is shown

in Fig. tn operation the canisters, moving with com

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Fela The draining rate andthe velocity Vp are acted

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HIGH-GRADIEN'! MAGNETIC SEP/

Scientific American 252, 46 (1175)

Arecent advance in the generation of strong magnetic fields opens

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One novel application of the now process is purifying wastewater by Henry Kolm, lola O'erteul Devid Kelland

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Feed Systeas for Solenoidel High-Gradient

Magnetic Saperators

JAAP. Vateon*

University of Salford, Department of Pure

?and Applied Physica,

Salford H5 4¥T, U.K.

* Supported by the Science Research Council, UsKe

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Introduction

igh gradient uagnetic separators consist of a ferro-magnetic wool natrix situated in a uniform tackpround magnetic field, wagnetic particles can be extracted, onto the watrix from a fluid carrying then through che vatrix, These magnetic separators have found commercial application in the clay industry 1, Usually, these separators are in the form of iron~ bound solenoids. The fluid passes through the pole cap and into a canister containing the matrix. The fluid passes tiirough the canister in a direction Parallel to the applied uagnetic ficld. In this type of separator, che power consunption is reduced by reducing L, the length of the solenoid. An increase in A, the cross-sectional area of the solenoid, does not affect the power consumption

as strongly as an increase in the length and has

the advancage that che voluue of material processed

in proportional to A. Consequently, iron-bound

solenoids, used for magnetic separation have the

solenoidal diameter greater than the length. The

production rate P of such a system is given by

P = pVoEAo/ (grity® D/T) a

where p is the mass of solids/unit volune of slurry,

Lf is the fraction of the solids entering the

separator retained on the matrix, Vp is the velocity

of fluid entering the matrix. The matrix occupies a

volune 1 - eg of the space in the canister, as the fluid velocity through the matrix is Voleg and for

a canister Lencth L, eke residence tine of the fluid

in the canister, 7, is T= egl/Vo. The free volune

in the canister eoiA, callel the canister volume, is

a convenient unit in which to express the volume of

slurry entering the separator; in equation (1),% is

the nusbor canister volunes, processed before cleaning the

matrix becones necessary. ic the nunber of

canister volunes of vater,, if any, used to displace

che slurry fron the canister, at the sane velocity

Yos prior to svitehing off the siapnetic field. Dis

the cead time, that is the tine calien to suitch off

the magnetic Held, clean the matrix and restore the

Held to the value at.wisich the process can be re~

started.

If TD, the production rate P becones P« to/ (My*Hlg)

that is P is largely independent of T. In these

circumstances, py 1, Yq aud £ being governed by

the details of the process, P can te increased by

increasing 4, provided 0/TSoiigrity. As suggested

above, this Consideration las °Lod to the design of

izon-bound solenoids, with the dianeter greater

than the length. On? the other hand, if D/Tootgeth,

P= NolA/D, then the production rate can be increased

by increasing L or A.

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Now consider the case of superconducting magnetic

ors operating at 37. The performance of

gor at ST vill be the same ax a separator

operating a lover ficld if the velocity Vg and

the agplied field Wy are increased in the same

ratio). This increased velocity reduces tha

residence tine T appreciably and the point where

D/T becones Large can only he off-net by a

reduction of 0, It is proposed that this be done

by aleernately using evo separate canister sysrens

in conjunction with a superconducting solenoid?,

0 that one ie in the magnet processing slurry

while the second canister systen is, being cleaned,

out of ?the field, D becomes approximately

equal to the tine taken to shift the canisters 4

Ia order to increase the production rate of the

superconducting separator che Length can be

increased until an optimum processing cost/

processed volune is reaciied, There is an optimum

because the cost roughly scales with che Length

but the production rate finally becomes independent

of Length when No*!l}>>D/T. The production can also

be increased by inereasiug the cross-sectional area,

unfortunately this is a auch more costly approach ths

@ increased lenth,

?There is then a need to have feed systems for a superconducting solenoids where the production rate increases wich the length.

In chis paper a radial feed system with this property Will be examined. 45 shown in Pig.2, the slurry is fed down a perforated tube centered along the axis of the solenoid. The slurry flows radially outwards chrough the holes in the tube, and into the recion containing the matrix. After passing through the satrix radially, the slurry returns, flowing parallel to the solenoidal axis, in an outer cylindrical annulus. :

In the next section the differential equations describing the behaviour of particles in a raiial system vill be examined and various approximate solutions will be considered, In the final section, the axial feed and the radial feed systens will be conpared.

---Page Break---

T1_theory,

The developsent of the theory of separator

closely parallel that for the axial feed aysten discussed

previously %

In Fig. a sector of the cross-section through a radial

canister system ie shown. The slurry is fe

at radius ty and leaves at radius rj. N(r,t) is defined

the number of particles per unit volune of the separator

that are present as captured particles at radius r at tine t.

R(e,e) ia the nusber of parcicles per unit volume of the

slurry. The sunber of suspended particles per unit volume

of the separator is © 2(r,t) vhere ? is the porosity of the

separator.

ete - Bw @

?o is the porosity of the clean bed and if the particles

hve volume v and a packing factor 8, che volune occupied

by N particles is siWv. For high gradient separators the

porosity is #0 high thar stv can be neglected.

If entrance velocity at radius r, is V; and at radius r

the superficial velocity V(r) is'given'by,

Ve) = eghyyle a

By considering the particle and fluid balance, at radius r,

at tine t in an elesent of thickness dr, it can be shown,

Lf diffusion in neglected, @

8 aN(eED/E + cg IRCELED/9E + eg VEE) ARCESED/IE = 0

This equation has been derived previously by Ives and Horner «

IE t is kept constant, an elenent of the suspension can be

folloved through the separator. On changing variables

equation (3) becomes,

8 GUE DI, +c, VE) GRE,D/2), = 0 (5)

?The rate of capture of particles is also equal to the

product of the total capture cross-section presented

to the slurry per unit Volune of matrix and the flux

of particles. In deriving this equation in the axial

case, it is acsuned that 2/3 of the matrix wire ie in

the Hongitudinal' configuratiod ; chat is, field and

flow parallel and perpendicular to the axis of the vire.

Thi jingle value of Rc, the capture radius

?The radial feed system is sore complex, a 1/3 of the

satrix is in the ?transverse? configuration, oth of

these configurations can be represented by a capture

radius, vuich behave physically

the cross-sections can be added, Watson has shown

the capture radius for the longitedinal and the

transverse configurations are almost. identical ?.

The axial cross-section is somewhat lover than the

tranaverse configuration®, ?In this work, the capture

radius Re is taken to be the average of ?the capture

fn the same way, so

---Page Break---

xadii from the tvo configurations, The kinetic equation can

be written

B ONCE DID = 4BeoC~eg)RR(E ye) VOE)/3na ©

R, can be written, for the case of high energetic fiel

abpropriate to the use of superconductors, as

Re = CV,G/V(r) a

C is a constant, V. = 2xR2MHo/9na appropriate to

particles of radius Rand suscepeibiiicy Xv eves of fodiue

?tod saturation magnetization fe with fleece vosceesi n

and an applied magnetic. field we? Cig 4 (ouey,veseeel

values fenging between 0 and 1 Sccavas' of ar meter tieh

SFiGion the wolung Of captured astersal ren anit erie

Satceierar ¢ ee in ear" wy Gr eae

hen NGL) =O; Gwe Le ae he wae eeay Ae

then from equation (5), (6) and (7) ve get, ?

(@R(ET)/9E), # ~ 4BCHEQ}O CH/nVCE)) RCE, x)/3ea (8)

For the clean separator G = 1, so equation (8) can be

integrated and gives, betveen'r) and 1),

Yo (RE21D/RQ) * = (4BC1~?,)0/ 38a) K (eg-r1) «

where Ry is the slurry concentration at the entrance to the

separator and where

Ke fe, Inv) 8691 (ear) (a0)

Equation (9) has exactly the sane mathematical form as in the

axial case), except that 1/V(c) has been averaged between fy" and

¥a and rg-ry replaces the length of the separator L.

Introducing the residence tine T and using equations (3)

and (10)

Te (= 2 /e¥, an

TH =H, (egnry), equation (9) becomes

18 (REE2,/Rg) = = 48 O/3e0) meg) HT a2)

This type of relationshiphas been observed in the case of

axial separators 10.

Jn the strong-coupling limit, it is

euned that

(4 $0/ 3ra) (1-c.)H,T >>1 which often aria

when Va >>V ge

The captured material can be regarded as having a sharp interfece. On the front side of the interface it fe assured that the filter has captured the waxiaun number of particles Ny and on the exit side of the interface no particles have been captured. This model has been discussed previously in connection with the conventional feed system,

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In calculating the position the interface it is a

wuned that

?AY, go that tig(s) © Ny (c/r)". The number of particles eatering the? separator In tine Lis '2erjVjRot. Assuming that

the position the interface is at r, at filter tine + then number

Particles which have entered and been captured {

2 My Bolt = Gr," ryDegt /2eqVy)

?he manor of capeced pertices can alto be writes

Bf ae ae = amy eg alr

ny

comparison with the nunber captured that ia if Rceity

then ac time +

RCE) (Egle? = Mey + G2) LEASED Ie a»

This equation must be solved simultaneously with equation (12)

duc with T replaced by 7,

2

Tyo ey (ey? = FD /eyhy an

IE (y42)(Vy/ey) (e/g) e <1 equation (13) can be approximated

by

Fo TEL YY, (Ryftipe as)

With equations (12) and (14) this gives .

Yn (ReEgyrD/R.) = = (6B(A-cQ)D/InadELT-ey m Ry/My) (16)

Here n is the sunber of canister volumes slurry which have

left the canister. This equation is identical in fore to

the conventional feed systen *=

I11__conparison between the convention, the radial syats

TE (#2) (Vy/ry) (RoMMy)e <1 the approximation which leads to

gauation (15) can not be'mde and equation (13) and (14) mst

be solved simultaneously. Movever dt can be argued that for aa

axial system and @ radial system, vhich have equal performance

when the separator is clean, then the separator having the

largest particle storage capacity will perform better as the

separator starts to collect material. If the separator parameters

are the sane then the conventional and the radial systems vill

have equal performance provided that HoT is the same in both

cases, This condition can be written

An HL

Hoey?

VV 2Evyn = Regn) a7

If the slurry flow rates are considered for the conventional

eyaten F and for the radical system F,. it can be

Pele = ® (eer) /AL + ryVo/t¥y

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If the quality of equation (17) is satisfied then F./F,>1+

?That is, if the initial performance is the sane, the flow

rate to the conventional system is higher, alchough the

difference is snall if Lv, >> TV,

The relative holding oapacity of the tyo systeas can be

determine? if it assumed the Np A(E)Y .. Tf the total

capacities for the conventional and radial systens are

Nz and tp respectively, then as)

Nel = Cey/t)? (9296822) S21DY NYA GS Pay CREAT

vhere S= rp/zy. Experimentally! it hae been shown that

Y= 1/2 and? for the two systens to have the sane initial

Performance equation (17) mist be satisfied. Also» when

the Evo eystens are to have equal capacity chen Ne/Mp = Le

Under these conditions equation (19) gives the re

in Table I.

(Lee show

Table I. Parameters at equal cepacity

yl,	wey
2	2.70
3	2.96
?	3.53
5	4.20

From Table 1, if rp/ry = 2, My> Ne Sf L/ey> 2.7. TE the Liry

ratio is increased, the storage capacity of the radial canister

becones relatively better for the condition where the initial performances are identical. However, the flov rate through

The conventional system is higher, but the difference decreases

as L/ry becomes larger.

In the case of English clays the conditions are different

those deseril

Te has been found that if the brightness gain is considered

?at equal numbers of canister voluse then the gain depends on

the value of A. The condicion for equal performance is simply

thee 3

aak 20)

Putting this condition into equation (19) gives

Neltig = (5/67) (8741) 4ST 1489/1) ay

with No/Mg #1 chen $= 5.76 which mean if r9/ry >5.74

LigoN and independent of the Length. Also vhen K= A then

V,¢¥, 80 equation (18) shows P_/Fq = r2/L. This means the redial canister has a much greater throughput than the

conventional canister if L >>r9.

---Page Break---

Fig. Captions

Figel

Fig.2

Fig.3

Conventional Feed aysten #1] V,

Radial Feed system x42 = ry? + x22

Field is

applied parallel to the axis.

Section through radial canister. Matrix is

between ry and x3.

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ROPROVENENTS OF A LOW-PTELD, HIGH-INTENSITY MATRIX SEPARATOR **

Je, P, waTSON *

DEPARTMENT OF PURE AND APPLIED PHYSICS

UNIVERSITY OF SALFORD

SALFORD MS GWT, U.K.

we Brit. Pat. App. Nos. 36476/77 and 46291/77

?+ Supported by the Science Research Council, U.K.

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1. Bergonuerzox

Avhigh gradient, lov field magnetic separator has been described

?and analysed previously 4, this machine consisted of a series of ers, holding a ferromagnetic wire vool matrix, which moved through a low magnetic field and from vhich a slurry wes slovly drained, The containers vere filled before they entered the field. In this process, paramagnetic particles can be captured fron the

slurry and held on the ferromgnetic matrix, the relative velocity,

between the slurry and the matrix betog or, The particles are released when the containers leave the field, Te was show that the faction of particles extracted depended on the ratio of the canister draining tine 1, to the ?characteristic magnetic tine 7,'.

1, = Sasaroy, a

where a is the radius of the ferromagnetic matrix wire of magnetization

A. P ie the fraction of space occupied by the mitrix wire and Vy,

the ?magnetic velocity a given by:

tang my ®

c

x is the susceptibility of the parmagnetic particles of radius R,

sumed in the analysis

H, is the applied magnetic ficlé. Tt was also

that R, the capture radius 2 depends Linearly on Ya/¥ so that:~

ao ov @

V is the velocity the fluid would have far avay from a single wire

ctual

and, for the case of the canister described here, it is the

velocity of the slurry surface as draining proceeds. -

© ie a parameter which depends on k = M/2u,fhy. Ta practice for fields greater than 27, C is practically independant of applied

field, but below 17, the increase in R, with M/2u,H, increases the

efficiency of separators

---Page Break---

?A high-intensity magnetic separator, vbich employs a ferromagnetic

wire matrix in a lov magnetic field, has been described and analysed,

previously. In this paper, the improvement in performance with the

reduction in magnetic field is shomm to be linited to the field H

where k (+ H/2ull,) becomes equal to unity, M being the magnetization

of the matrix strand: ble to

However, it ie shown that it is po

obtain further improvenents in performance,at magnetic fielde lover than

etic matrix. This involves firet

this Linityby the use of an hy

jgnetizing the matrix in a high field before reducing the field to a lo?

operating value, which may even be zero, The captured material is renoved

after the matrix is denagnetized.

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However, the largest value of k that can normally be obtained vith

the soft ferromagnetic stainless steel is k= I,due to the large denagnetizing factor of vires of circular or almost circular cro

factor Limits

section magnetized perpendicular to th

the maximus efficiency of the moving watrix separator to approxinately

the field at which the matrix becomes saturated. It is the purpose

of this paper co investigate, in more detail, the behaviour of R, at low

magnetic field and to suggest, that the use of materiale with high

coercive force can move the maximum efficiency of the moving matrix

separator to very much lover applied fields.

?The next section discusses the behaviour of the particle-wire

interaction at fields mich less than the field required to saturate

the matzix. The introduction wire vith a high coercive force is

considered and then an atteapt to evaluate the performance of Likely

structure of machines

materiale is made. In the final section, the which use thie technique is considered,

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2.TuoRy

?A theory of capture of paramagnetic particles has been developed

152) 4 5+ © besed on the interaction between a paramagnetic particle

carried by a fluid past a ferromagnetic wice magnetized by a unifors

applied magnetic field ¥,. By studying the equations of motion, the

particle trajectories striking the wire can be found, which allows the

capture cross:

ction 2R e/unit length of the wire to be determined.

The capture sadiue R, vas found to depend on k and on V/V

Cowan ea have ?found that , provided Vn Mo< ?2

Ry can be write

= aD OWN, + AID o

?As shown in Equation (4), vhen V,/V, <1 and V/V, decreases in

value, the term kWI/V, becomes the dominant term, especially when k

fs large. or exanple, when V./¥, = .1 and k= 1, the second corm in

4 factor of 3 greater than the firet. In the magnetic procensing of

clay, the values of V/V, are usually much Less than .1 Ta the following

simple anatysis therefore, equation (4) is approxinated by:

ae 2) ATT ©

When 2 cylinder of circular eros!

ction,is magnetized by an

applied field H,,then che actual internal field 8, fe appreciably aitterent Fromthe applied field H.,due to the mesos of etre

de-magnetizing fiel@, 20 that

By = = Wau, ©

where M is the magnetization of the cylinder. If the vire has a

permasability » > #,chen the magnetization M in given by

Me yl G4 yn t 2, 2)

ur 1. At lowtleld H,, the magnetization is therefore detersined

where x

by the reciprocal ?of the de-magnetizing factoryand k has the value k = 1.

If the waterial is hysteretic,vith a coercive field i, the

Mie

magnetization on the de-magnetizing part of the cycl

M= 0 at H =H, 90 that at low applied Fiatae.

---Page Break---

wea ay enp »

at

bere o

svesebesapnate valectey ¥, can be weteten

erty en? a0)

at

Bee Ak wa BY ay

tare

A= 9) xR y,/nay/? » constant

?An examination of equation (11) reveals & vay in vhich the operation

of the lov field system can be done, The quantity V,/i,? {a a measure, for =

siven value of B., of the voluse of material processed per mit pover cont, Tals is because the volume of material procassed/sec ia

proportional to V, and the pover cost is proportional to ¥,?

equation (1) ve have,

a2)

Te W, Se reduced, but V,/H,7 is kept constant, then, in the absence

of hystereaia, X and consequently B,slovly increase with

deccansing field,until k reaches the maximum value of k=

this point,there is no? increase in BL produced by lovering

Beyond

walus of, at constdat pover/unit volues of processed material.

?This point ia daterained by the details of the magnetization curve

smd by the eliza of de-mapnetizing factor and is 1

2 than, but

eppraxinately aqual to, ¥,/3y,.vhere My Ls the saturation magnetization.

Ta contrast if the de-magnatization branch of the curve is ~

cousidered, then k fncraasen vith decreasing Hy, as shown by Bquatis

(9). TE the power/procensed unit volume is held constant, while By

pe

in decreased, thea He teres and consequently, at constant

pover/processed unit volume, the performance of the separator can be

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appreciably increased as E, ia reduced. For example, if = Re,

and Sf ve compare the magnetization branch vith the de-ungnetization

branch then the values of k are 1 and 2 respectively, From Equation

aD ,we

that 8,7 is increased by a factor of 8 on the de-nagnetization

branch relative to the magnetization branch. It seems Likely therefore,

that the field B, can be reduced so that permanent magnets can be used

to supply B,yand perbaps H, can even be reduced to zero.

Te ie interesting to com

jer the properties deoiced in a matrix

for operation in a separator. As ve have seen, the most inportent

requirenent is # large coercivity #,. The second most magnetic

important property is # large permeability near the operating fielé

So, this ensures that the magnetization has the maxima value alloved by the demagnetizing factor.

?The eird factor is mechanical one, the material must be ductile

eo that the matrix can be formed into wires or sbeete, A List

containing suitable alloys {2 given in Table 1.

Table, 1 - Alloys suitable for lov field separation® .

Nese Couposition * coercivity? | orep. [eat pach.

Teese. Presse

Vicatloy 2 [60 14v sto pone h

Dusit, | p,2600 1)

unite 1 acer, po, Browse

Gatgeceotten)|20ni60ce sso Rasmta

: * pooch >

unico 1 _|2aniascesocs | 700} >

at O.2%pnd if hysteresis is used,

?hen for Viealloy 2, Gunite 1 and Gunico 1,the values of k are 1.25,

1.3 and 1.35, respectively. If the processing fs done without using

hysteresis then k= 1y 1¢ hysteresis is used, then from Equation (22),

Af R, and Hare held constant,then the processing velocity can be

increased by a factor of 1°. These factors are 2, 2.2 and 2.5 for the

three alloys, respectively. This leads directly to a change in the

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pover cost per unit volume hich varies inversely with k° omely,

0.5, 0.45 and 0.4, respectively.

a

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L

3. Magnetic Separators

Im order to take advantage of the lov power cost/unit voluse

processed, it in necessary to use a hysteretic matrix material. In

the moving matrix system 1, the folloving procedure may be adopted.

?The canister, which is one of a large musber, containing an hysteretic

satrix is {{lled with slurry. The container is moved into # high magnetic

ffeld region and slow draining of the slurry comenced. The container then moves betveen the poles of a lov field magnet in vbich mat of

?the draining is done, The lov magnetic £ield may in some cases be

Reduced to zero, When draining is completed, the canister passes

Sato a section where the matrix is de-magnetized by an alternating

sagnetic field of decreasing magnitude, The retained particles can then be washed from the matrix. This machine cousiste of « chain of coutiners, consequently the operation is continuous.

1t should be pointed out that an hysteretic matrix can be used

with any magnetic separators hovever, in many cases, the gein in

processing velocity or performance, resulting fron the increase in

k, may be so snall that it does not varraht the extra complication,

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