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HYDRODYNAMICS OF HYDRATE SLURRIES IN PREPICIPATORS APPLICATION TO PRECIPITATORS DESIGN

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Abstract

A theoretical study of hydrodynamic behaviour of hydrate slurries in high solids content tanks leads to represent precipitators by simplified diagrams including mixers, reactors, recirculations, bypasses. Radioactive tracing helps precising where the imperfections in the design come from. In Friguia plant, we put in evidence 2 types of bypass :

• the first, basically bound to the stirring technology,
• the second, which can be eliminated, due to a bad mixing between feed an stirring flows.

After the hydrodynamic analysis, we apply a mathematical model which can predict solids content and grain size distribution within the tanks (often quite different from the feed). Some industrial and calculated results are presented.

1 - Introduction

Prédiction of actual precipitation kinetic of a plant file needs following informations :

a) kinetic equations, from batch laboratory experiments, allowing to calculate results for continuous reactors, perfectly stirred or plug flow

b) hydrodynamic behaviour of the tank

c) solids content and grain size inside the tank.

This paper is related mainly to points b) and c) ; point a) has been established for a long time [1].

Chapter 2 summarises results of precipitators' hydrodynamic at Friguia plant, determined by radioactive tracing [2].

Chapter 3 describes how various precipitators technologies can be described by a simple association of mixers, plug flows, recirculation, bypasses.

In chapter 4, theoretical considerations to calculate solids content and grain size inside the tank are presented ; some experimental results are given.

2 - Precipitators hydrodynamic at Friguia plant [2]

Radioactive tracing technique had been successfully applied at Friguia plant to demonstrate a very important short-circuit related to

- the position of the slurry outlet with regard to the feed inlet
- the relatively high value of the ratio feed flow/stirring flow.

Experiments were carried out on 2 precipitators files both air-lift agitated. One (unmodified) is equipped with precipitators represented on fig. 1 ; the other one (modified) had identical tanks, except position of feeding, which is immersed at -2 m.

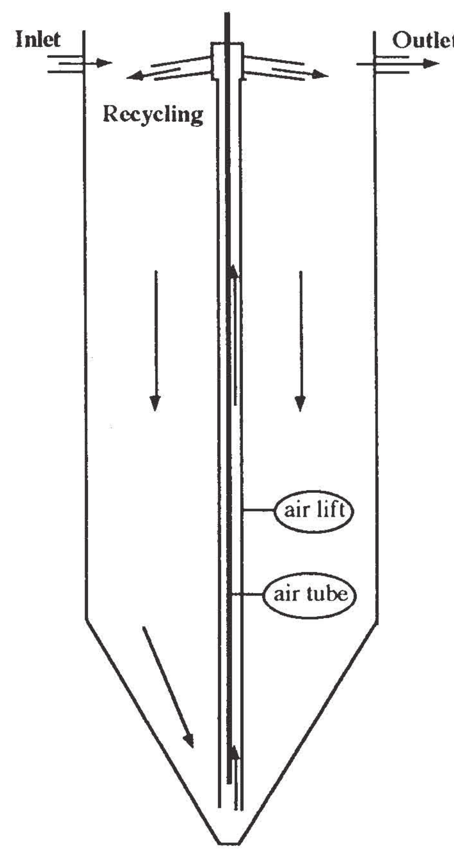

Figure 1 : design of original precipitator

A stirring flow of 1 670 m^3/h was found, confirming a plug flow in the cylindrical part of the tank, wich is the most important fraction of volume.

Short-circuit analysis gave results in table 1 :

Short-circuit, in % of total flow	
unmodified	55
modified	42

Table 1 : short-circuit of precipitators files

3 - Flow diagrams of various precipitators technlogies

Fig. 1 precipitator can be represented by the simplified flow diagram of fig. 2 :

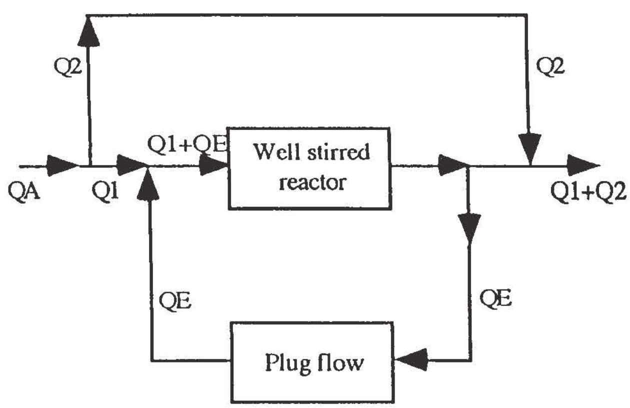

Fig. 2 Flow diagram of precipitator of fig. 1.

QA : slurry flow, inlet
Q2 : slurry flow short-circuiting directly the tank
Q1 : slurry flow entering the tank
QE : stirring flow.

Total short-circuit is the sum of :

- direct short-circuit, Q2
- fraction of Q1 flow going out directly after good mixing with QE flow. This fraction is Q1/Q1 + QE

we have, then, the 2 equations :

(1) $QA = Q1 + Q2$

(2) $KQA = Q2 + \dfrac{Q1}{Q1 + QE} \bullet Q1$

K, total short-circuit coefficient.

Application to Friguia results :

QA = 1 078 m^3/h

QE = 1 670 m^3/h

* Unmodified file. K = 0.55 (table 1)

Total short-circuit : 593 m^3/h

Q1 = 684 m^3/h (199 going out directly after mixing with stirring flow)

Q2 = 394 m^3/h

* Modified file. K = 0.42

Total short-circuit : 453 m^3/h

Q1 = 1 000 m^3/h

Q2 = 78 m^3/h

Immersed feeding at -2 m made it possible to decrease by 80 % the direct short-circuiting of the tank.

Total short circuit is 453 m^3/h, very close to 423 m^3/h which is the short-circuit with Q2 = 0, corresponding to 100 % of the slurry flow entering the tank ; this short-circuit is unavoidable.

The tank is represented by the flow diagram of fig. 3 :

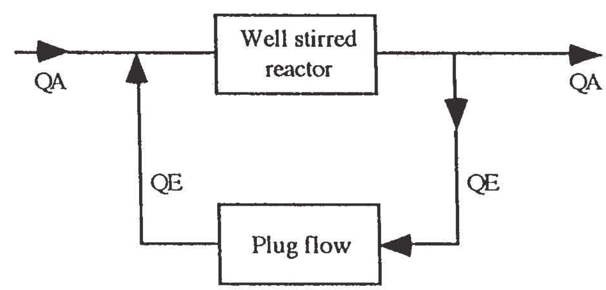

Figure 3 : flow diagram of tank with no direct short-circuit

It is important to understand that hydrodynamic performances can only be improved by modification (increase) of stirring flow.

Bottom discharge precipitator

Design is represented on fig. 4, and corresponding flow diagram on fig. 5

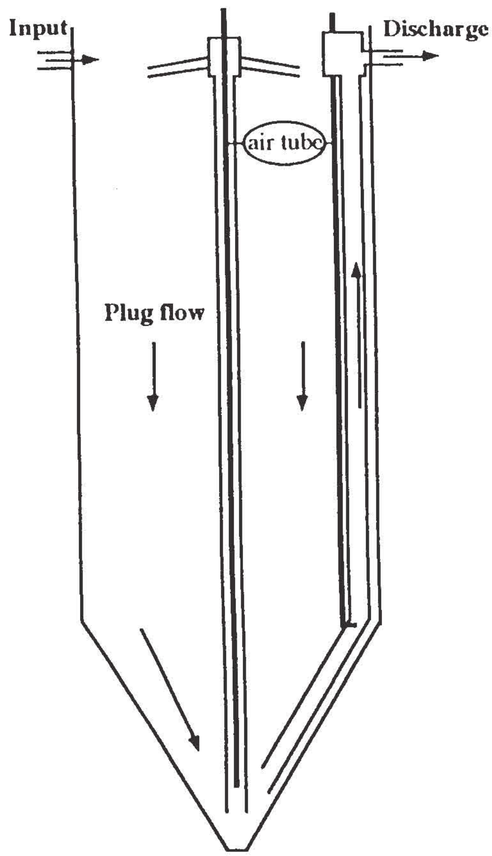

Figure 4 : bottom discharge precipitator

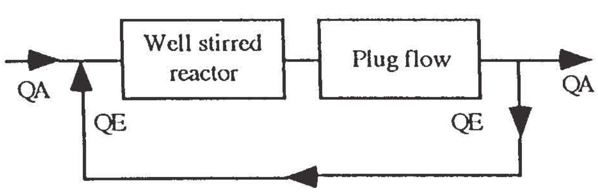

Figure 5 : diagram of bottom discharge precipitator

This tank is profitable only if QA and QE are very close.

- When QA << QE, the tank performance will approach a perfectly stirred tank, and the bottom discharge does not lead to a significant improvement
- When QA >> QE, the tank is a plug flow reactor : agitation can be suppressed. It is the most efficient configuration, giving the highest productivity. Particle velocity in the cylindrical part is lower than in an agitated tank, but not very much. Velocities in both cases are about some meters/hour.

4 - Solid content and grain size inside the tank

In all described technologies, flow in the cylindrical part of the tank is slow. We put in evidence, by a theoretical study validated by industrial trials, that solids content of circulating flow inside the tank was lower than in feeding slurry, and grain size finer. This phenomenon is called expansion ; in the case of an ascending flow, it is called contraction : solids content inside the tank is higher than in feeding slurry [4]. These phenomena take place when liquor's velocity is close to particles' velocity ; each particle size has its own residence time in the tank.

4.1. Theoretical considerations

Let WØ the settling velocity of a particle of diameter Ø, with respect to liquor velocity.

A reduced velocity VØ is defined, by multiplying WØ by a factor taking into account solids content of the slurry :

$$V\varnothing = W\varnothing \frac{DL}{DL + 1/2.42}$$

DL is dilution, expressed as m^3/ton of dry solids.

If MS is the solids content, in ton/m^3 of slurry,

$$DL = \frac{1}{MS} - \frac{1}{2.42}$$

(2.42 is density of aluminium trihydrate)

It is useful to introduce V100, reduced velocity of a particle of 100 μm diameter ; V100 can be calculated independently, or experimentally determined :

$$V\varnothing = V100 \left(\frac{\varnothing}{100}\right)^2$$

Grain size

It is useful to introduce the quadratic diameter of particle size distribution :

$$dq = \left[\sum_0^\infty a_i \, \varnothing_i^2\right]^{0.5} \quad , \; a_i \text{ is weight \% less than } \varnothing_i$$

X (I) : weight % of particles in feeding slurry, in the diameter range I - 1, I ;

Y (I) : weight % of particles inside the tank, for the same range.

Results

Calculations are based on particles flow balance in steady state, and allow to determine particle size and solids content inside the tank :

$$(3)\ Y(I) = \frac{X(I) \bullet DLB}{DLA} \times \frac{1}{\left[1 + \frac{S\,V100}{QL}\left(\frac{I}{100}\right)^2\right]}$$

$$(4)\ DLB = DLA\left[1 + \frac{S\,V100}{QL}\left(\frac{dqB}{100}\right)^2\right]$$

S : Tank section
QL : Liquor flow in feeding slurry
DLA, DLB : Dilutions in feeding slurry and inside the tank
dqB : Quadractic diameter of particle size distribution
: inside the tank.

4.2. Examples

* Non agitated tank. La Barasse plant (1986 - 1987)

$S = 113\ m^2$
Slurry flow, feeding : 350 m^3/h (QA)
Solids content : 600 g/lit (MSA)

For different particle size distribution in feeding slurry (dqA), table 2 gives solids content (MSB) and grain size (dqB) inside the tank :

dqA (μm)	121	103	93	88
MSB (g/l)	378	418	450	477
dqB (μm)	105	94	87	80

Table 2 : Solids content and particle size in a non agitated tank

For other conditions : QA = 460 m^3/h
MSA = 650 g/l

results are given in table 3 :

dqA (μm)	121	103	93	88
MSB (g/l)	469	512	534	553
dqB (μm)	109	96	88	82

Table 3 : Solids content and particle size in a non agitated tank

* Industrial trial, Friguia plan.

QA = 1 200 m^3/h
MSA = 650 g/l
S = 113 m^2
Solids content measured inside the tank : 535 - 578 g/l
Theoretical calculation : 576 g/l

Experimental validation demand precise sampling at different levels in the tank. We built a special device consisting of a bottle equipped with two rubber valves, which open and close by air pressure.

Miscellaneous observations :

-Samples picked up in paddle agitated tank exhibit the same expansion phenomena than in air-lift agitated tanks.

- Expansion phenomena are exacerbated by slow velocities, low solids content in feeding, high temperature, coarse grain size.

Conclusion

The representation of various precipitators technologies by simple diagrams, allow to predict actual plant precipitation yield, provided expansion phenomena are taken into account.

Expansion phenomenon are also an essential parameter in designing transfer pipes and stirring equipments.

Radioactive tracing is an efficient way to determine a tank hydrodynamic ; the technique, associated with a monitoring of the tank with a special sampling bottle give more quantitative information on expansion phenomenon leading to the settling velocity.

The methodology described in this paper can also be applied to evaluate alumina thickeners performances.

References

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