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SUBJECT: Review of the HRT-CP Hydroclone System
TO: W. L. Carter
FROM: H. E. Williamson

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To: W. L. Carter
From: H. E. Williamson
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Date: September 30, 1955

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DATE FEB 19 1957 *OK*
For The Atomic Energy Commission
H. F. Canale
Chief, Declassification Branch

1.0 Summary

As a result of the flowsheet revision made to incorporate the advantages of induced underflow recirculation, it is necessary to review the characteristics of the HRT hydroclone system. The results of a study on the revised HRT hydroclone system are illustrated in Figs. 2, 3, and 4.

It seems advisable to operate the hydroclone a large fraction of the retention tank cycle time (at least 90%). The best hydroclone size and underflow to feed rate ratio seem a matter of conjecture at this time. It is suggested that a good design choice is a 400 mils diameter hydroclone designed for an underflow to feed ratio of 1%, with provisions for replacement by a smaller unit.

2.0 Introduction

The discovery by M. E. Whatley of induced underflow currents in a retention vessel attached directly to the hydroclone underflow port has led to flowsheet revisions for the HRCF. Instead of recirculating the underflow stream through a retention tank and back to the hydroclone feed, flow through the retention tank is maintained by the circulation current generated by the hydroclone. The advantages realized by the new system are a reduction and simplification in control requirements, relocation of the pump to the relatively solids free overflow, and a potential reduction in the reactor solids concentration. The latter is made possible by the lower ratio of underflow to feed rate that can be attained with induced underflow currents.

A study of the HRT hydroclone system made by C. E. Guthrie was reported in CF 55-1-153, but with the recent revisions it seems desirable to review relationships between reactor solids concentration and hydroclone design and

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operation. Many of the ideas used in this memorandum resulted from discussions of the subject with M. E. Whatley and J. R. Engel.

3.0 Flowsheet Discussion

The primary operation in the chemical processing of the HRT fuel is solid-liquid separation by centrifugation in a hydroclone. A small "soup" stream is taken from the reactor, circulated through a hydroclone and returned to the reactor minus the fraction of insoluble fission and corrosion products that have been removed.

The solids in the feed stream from the reactor are concentrated into a retention tank attached directly to the underflow port of the hydroclone. This tank is discharged periodically, then filled with fresh "soup" solution that flushes into the reactor system replenishing the burned fuel. The size of the tank and frequency of discharge are chosen to duplicate the purge rate that would be needed in a large scale power producer to remove soluble fission products and contaminants from the reactor system.

4.0 Experimental Work

Experimental work on small hydroclones has been performed using suspensions of ThO_2 in water; it is expected that fission and corrosion products in hot "soup" will behave similarly. Data as obtained have been reported in the Unit Operations Monthly Status Reports. However, these data, applied primarily to comparison of various designs, have used gross efficiency measurements. M. E. Whatley has stated⁽¹⁾ that "the use of gross efficiency data on one material to predict performance of the clone on an untried material, even when the particle size distribution of both materials is known cannot be done quantitatively. The relation which must be known for predicting performance is the clone efficiency for each particle size or, the particle size point efficiency curve." Difficulties have prevented the determination of this curve. This work has confirmed the opinion that the smaller the hydroclone diameter the smaller the particle that will be separated from the feed stream.

Generally, the efficiency increases as the feed pressure increases and as the diameter decreases. However, it is felt that (for fabrication) a practical lower limit was reached with the 250 mils diameter hydroclone.

(1) ORNL CF-55-1-194, Monthly Progress Report, Unit Operations Section, Chemical Technology Division, January, 1955.

5.0 Hydroclone Selection

There is not enough information available to discriminate between sizes of hydroclones with respect to their tendency to plug, but since a larger unit has larger ports, it seems advisable to base the flowsheet at this time on the characteristics of a 400 mils diameter hydroclone. This by no means rules out the smaller unit, and some of the following calculations were made for both sizes.

The choice of the larger hydroclone is easily justified since there will probably be very little sacrifice in separation efficiency. If the particle sizes are distributed rather evenly between 10 and 0.1 microns, the efficiencies of the two are essentially the same. For particles greater than 4 microns, their efficiencies are both quite good, for particles less than 0.2 or 0.3 microns neither show much solid-liquid separation. However, for 1 micron particles the efficiency of the smaller hydroclone under certain conditions is about 70% while that of the larger under similar conditions is only 10 or 15%. This is expected since 1 micron is near the critical diameter for these hydroclones. The critical diameter is that particle size which reports half to the overflow and half to the underflow. It varies about directly with the diameter of the hydroclone, being about 0.8 to 1 micron for the smaller unit and between 1.3 and 1.6 micron for the larger unit. Thus it can be seen that the smaller hydroclone offers a large advantage only if the particle size distribution is peaked near 1 micron.

6.0 System Characteristics

The concentration of solids in the reactor will depend on the hydroclone efficiency, its operating cycle, the relation between certain flow rates and volumes, and the rate of solids production.

The solids concentration in the reactor can be calculated with the following formula derived by M. E. Whatley and modified slightly for convenience. It is assumed that solids in the retention tank are homogeneously distributed.

$$1) \quad X(\theta) = X_0 + \frac{k\theta}{V_R} \left[1 - \frac{E_1 R}{E_1 R + P(1-E_2)} \right] - \left[\frac{E_1 R}{E_1 R + P(1-E_2)} \right] \left\{ X_0 - \frac{k}{V_R [E_1 R + P(1-E_2)]} \right\} \times \left\{ 1 - e^{-[E_1 R + P(1-E_2)] \theta} \right\}$$

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$X(\theta)$ = solids concentration in the reactor "soup"

X_0 = reactor solids concentration at start of hydroclone operation

k = solids production rate

θ = time hydroclone has been operating

V_R = volume of the reactor

F = flow rate to hydroclone

$R = \frac{F}{V_R}$

V_P = volume of underflow retention tank

$P = \frac{B}{V_P}$

E_1 = probability a particle in the feed stream will be separated into retention tank

B = underflow rate to retention tank

E_2 = probability a particle in stream leaving retention tank will be returned to tank.

The reactor solids concentration at the start of a hydroclone cycle is obtained by the following:

$$2) \quad X_0 = k \left[\left(\frac{V}{E_1} \right) \left(\frac{\frac{E_1}{V} + \frac{W}{V_P} (1-E_2)}{1 - e^{-[E_1 R + P(1-E_2)] \theta_C}} - \frac{\theta_C}{V_R (1 - e^{-[E_1 R + P(1-E_2)] \theta_C})} + \frac{1}{V_R [E_1 R + P(1-E_2)]} \right) \right]$$

V = period time elapsing between retention tank discharges

θ_C = amount of time hydroclone is operated between retention tank discharges.

$W = \frac{B}{F}$ = underflow ratio

For the HRT, certain of these parameters are established; they are the reactor volume, and the retention tank volume and frequency of discharge. The reactor

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volume is about 455 liters, the retention tank 7.56 liters, and the discharge is weekly.

The capacity of a hydroclone depends on the size of the unit, design, and available driving head. The flow rate to a hydroclone varies directly as the square root of the pressure differential imposed between the feed and overflow. For geometrically similar hydroclones the capacity varies directly as the square of the diameter. This is illustrated in Fig. 1 for two units that were almost geometrically similar.

The separation efficiency increases with increasing pressure differential between the feed and overflow. In view of the lack of information on expected particle size, as high a pressure differential as practicably possible seems advisable. Feed to overflow pressure differential is the most important of the operating variables. A design minimum of 100 feet of liquid has been established; the capacity at this pressure is taken for design calculations.

The ratio of the solids concentration in the retention tank to the concentration in the reactor system, will reach a maximum at some time after the start of hydroclone operation. This maximum concentration ratio will increase as the ratio of induced flow to hydroclone feed rate is decreased, in turn decreasing the maximum reactor solids concentration. The change is not pronounced at higher probabilities of retention, as shown in Fig. 3, and as the induced flow is decreased it takes longer to flush the fresh "soup" from the retention tank into the reactor system, as shown in Fig. 4. Also, the ratio of induced flow to feed rate is built into the hydroclone by aptly designing the cone length and port sizes; there is a practical limit when fabrication and freedom from plugging difficulties are considered. This may be as low as 0.5%, but conclusive tests have not been run. There seems little reason to consider underflow rates less than 0.5% and if high probabilities of retention are expected, it may be reasonable to go up to a 2% underflow ratio.

The maximum reactor solids concentration was calculated for different conditions using equation (2). The information obtained is illustrated in Fig. 2, which shows the effect on the maximum reactor solids concentration of operating two different size hydroclones varying percentages of the retention tank cycle time. The maximum reactor solids concentration is normalized to unit solids production in grams per day.

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This figure may be used to estimate the solids concentration of all or a specific element. Several values of particle removal probabilities, E , were used as the actual value of this parameter is dubious. Table 1 is a portion of a table presented in a recent report⁽²⁾, and is shown to illustrate the variations of removal probabilities with particle size. To keep the calculations from being unreasonably complex, it was assumed the removal probabilities were constant with time. This obviously will not be the case since the larger particles will be selectively removed altering the particle size distribution, but with existing uncertainties about particle size and growth, this seems quite reasonable for a qualitative calculation. In addition, settling, neglected here, will have an effect similar to increasing the value of E_2 .

An underflow rate, W , of 2% was used, but the effect of varying this is shown in Fig. 3.

Assuming complete and instantaneous mixing in the underflow retention tank the time required to flush a high percentage of the fresh "soup" charge from the tank was calculated from the following equation (3) and the results shown in Fig. 4.

$$3) \quad M = (1 - e^{-P\theta}) 100$$

where: M = percentage of flushing.

Unit Operations tests under conservative conditions indicate that complete and instantaneous mixing is approached through agitation by thermal and induced currents.

7.0 Conclusion

The most important conclusion to be drawn is the advisability of operating the hydroclone a large percentage of the retention tank cycle time. This should mainly reduce the level of biological hazards in the pressurized system and the reactor operating time required to reach an equilibrium solids concentration. This ignores the potential problem of retention of the particles in the reactor system by settling or adhering to surfaces.

(2) ORNL CF-55-5-179, Monthly Progress Report, Unit Operations Section, Chemical Technology Division, May 1955.

At present the decision between the use of a 250 or 400 mils diameter hydroclone is largely a matter of conjecture. It is very probable that this will be resolved only by a test in the chemical facility once the reactor is operating. The smaller unit shows advantage only if the particles formed in the reactor system are mostly in the order of $1\ \mu$.

The lower the removal probabilities, E_1 and E_2 , the more influence the underflow to feed rate ratio has on the reactor solids concentration. Thus, lower expected removal probabilities dictate lower underflow to feed rate ratios. However, other considerations, fabrication, plugging, and retention tank flushing establish lower limits depending on the size of the hydroclone.

HEW/nh

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Table 1
Hydroclone Performance in the Induced Underflow Pot System

Hydroclone Dimension (4(U)HH)

Nominal diameter	0.25 in.
Feed inlet	0.063 x 0.033 in.
Vortex finder	0.053 in i.d.
Underflow port	0.075 in. i.d.
Cone length	1.5 - in.

Operating Conditions

Feed pressure	35 psi
Feed flow	0.20 gpm
Underflow ratio	1.98%

Solid Material ^a size u	E ₁ %	E ₂ by dilution %	E ₂ direct %
1	26	52	49
1	29	--	--
2	35	46	66
2	50	--	--
4	95.8	90.1	94.0
4	96.8	95.7	94.3

^a Approximate average.

FIGURE 1. CAPACITY OF HYDROCLONE VERSUS
PRESSURE DIFFERENTIAL BETWEEN
FEED AND OVERFLOW

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FIGURE 2. REACTOR SOLIDS CONCENTRATION AS A FUNCTION OF HYDROCLONE OPERATION
 $\Delta P = 100 \text{ FT.}$

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FIGURE 3 REACTOR SOLIDS CONCENTRATION
AS A FUNCTION OF INDUCED
UNDERFLOW RATIO

FIGURE 4 TIME REQUIRED TO FLUSH FRESH FUEL INTO REACTOR SYSTEM

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