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SUBJECT: Homogeneous Reactor Processing:
Considerations in Applying Liquid-Solid Cyclone
Separators to Homogeneous Reactor Processing

TO: F. L. Culler

FROM: M. E. Whatley

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For The Atomic Energy Commission

H. R. Canale

Chief, Declassification Branch

HOMOGENEOUS REACTOR PROCESSING:
CONSIDERATIONS IN APPLYING
LIQUID-SOLID CYCLONE SEPARATORS TO
HOMOGENEOUS REACTOR PROCESSING

By
M. E. Whatley

Photostat Price \$ 3.30

Microfilm Price \$ 2.40

Available from the
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Solid-liquid cyclone separators are being studied for use in separating the precipitated solids from nuclear reactor fuel solutions. Tests made with a commercial unit, the DorrClone TM-3, at atmospheric pressure and room temperature indicate that the likelihood of success is good. The development of designs amenable to reactor conditions is being pursued. The need exists for a unit of high efficiency to operate at feed flows on the order of 0.1 gpm.

The engineering specifications on the device for removing precipitated solids from reactor solutions are the same as those placed on other reactor components; the device must be completely leak free, operate with virtually no maintenance, and have a long life. Since a stream of considerable flow is to be processed, it is expedient to operate the device at the pressure of the reactor, obviating a letdown system and return pump. Of the three types of devices which might be used, a filter, a centrifuge, or a liquid cyclone, the liquid cyclone alone has the advantages of being easily built to withstand high pressures with no leakage, and has no moving parts to require maintenance.

The liquid-solid cyclone uses an inlet jet tangential to the wall of a chamber of circular cross section and a centered overflow through which the clarified liquid must pass. In progressing from the wall of the cyclone into the overflow, the conservation of angular momentum gives the liquid an extremely high angular velocity at a small radius, resulting in a high centrifugal field. The solid particles are thus forced against the inward flow of liquid and carried by a secondary flow to an underflow discharge port. It is characteristic of the liquid cyclone that the centrifugal field which effects the separation also generates a pressure which must be overcome in moving liquid through the unit. A substantial pressure loss is therefore unavoidable in using an efficient liquid-solid cyclone.

Another disadvantage of the liquid cyclone is that it is equivalent in function to the operation of settling, and the smaller particles whose settling rates are slow will be carried through the device with the clarified liquid. Current designs are able to separate material on the order of one micron in size with reasonable efficiencies, but the efficiency drops off rapidly for smaller material. In the operation of a liquid-solid cyclone there appears to be an optimum ratio of underflow to feed rates of about 0.1. When this ratio becomes as low as 0.06 the efficiency of particle removal decreases. Increasing the ratio above 0.12 effects little increase in efficiency while the concentration factor achieved is decreased.

In order to effect concentration factors on the order of 800, as desired in the reactor processing installations, it is necessary to use some cascading or recycle scheme involving several cyclones. In Figure 1. are diagrammed five methods of using multiple cyclone cascade combinations and the theoretical relative power requirements for each based on 10% liquid to the underflow. The recirculating pumps are not shown. For the

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**Relative Power
Requirements**

1.	1.00
2.	3.15
3.	4.46
4.	1.23
5.	3.86

Figure 1. Some Cyclone Cascade Combinations

Figure 2. EFFICIENCIES OF FIVE CASCADE COMBINATIONS OF LIQUID-SOLID CYCLONES AGAINST THE EFFICIENCY OF THE UNIT CYCLONE

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FIGURE 3. CONCENTRATION RATIOS FOR FIVE CASCADE COMBINATIONS OF LIQUID-SOLID CYCLONES, WHERE $B/F = 0.1$, AGAINST THE EFFICIENCY OF THE UNIT CYCLONE.

case where the particles are uniform, making the efficiency of all the unit cyclones in the combination the same, the overall efficiencies and overall concentration ratios have been calculated and are plotted in Figures 2 and 3 respectively as a function of the efficiency of a single cyclone.

For combinations cascaded to the overflow alone, like combinations (2) and (3), the efficiency is greatly increased, but the concentration ratios are still in the order of that obtained from a single cyclone. The power requirement is higher than the number of cyclones times the power requirement for a single cyclone because of the recycle. When the cyclones are cascaded to the underflow alone, the efficiency falls below that for a single cyclone, but high concentration ratios are achieved. The power requirement is slightly higher than a single unit. When the arrangement is made such that the cyclones are cascaded both to the underflow and overflow, as in combination (5), both high efficiencies and high concentration ratios can be realized. It is noted, however, that when the efficiency of the unit cyclone becomes less than 60%, the efficiency of the combination decreases rapidly, becoming less than the unit cyclone at an efficiency of 50%.

Another method of achieving high concentrations is to recycle the underflow stream to the feed until the concentration builds up sufficiently. If the cyclone were perfectly efficient, one unit could be used, and the product removed at the proper rate to give the desired concentration. Figure 4 shows four methods of using this type of build-up recycle, and Figures 5 and 6 give the efficiencies and concentrations respectively. In all cases, the individual cyclones were operated 10% liquid to underflow and the combination was operated at 0.1% of feed liquid to product.

It is readily apparent that the use of only one cyclone is not practical since, when the efficiency of the unit drops even to 90%, the combination efficiency is less than 8%. The use of three stages cascaded to the overflow, as in (7), does well at high efficiencies, but fails rapidly when the unit efficiency becomes lower than 80%. This combination also has the disadvantage of a very high power requirement because the bulk of the stream must go through all three of the stages.

Arrangements (8) and (9) are similar to (7) in that two stages are cascaded to the overflow with build-up recycle, the difference being that these two stages are fed from the underflow of a preceding clone. Arrangements (8) and (9) differ in that (9) returns the overflow of the concentrating cascade to the feed of the first clone, and (8) does not. The decision in this depends upon whether the overflow stream in question is more concentrated or less concentrated than the feed. Since this overflow stream is always more concentrated than the raw feed stream, arrangement (9) is superior. This arrangement is seen to maintain higher efficiencies and higher

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Relative Power Requirements

6	1.35
7	3.71
8	1.23
9	1.39

Figure 4. Some Cyclone Recycle Combinations

Figure 5. EFFICIENCIES OF SOME BUILDUP RECYCLE COMBINATIONS OF LIQUID-SOLID CYCLONES AGAINST THE EFFICIENCY OF THE UNIT CYCLONE.

Figure 6, CONCENTRATION RATIOS FOR SOME RECYCLE COMBINATIONS OF LIQUID-SOLID CYCLONES AGAINST THE EFFICIENCY OF THE UNIT CYCLONE.

concentration ratios through decreasing unit efficiencies than any of the other build-up recycle arrangements considered. It is not, however, from theoretical considerations alone, superior to any of the discussed combinations which do not use build-up recycle.

In addition to the theoretical considerations, there are several important practical aspects of applying a cyclone cascade to a reactor. First, a high efficiency is not necessarily essential, since the same effect can be obtained by increasing the processing rate. Of course, the concentration ratio must be increased by the same factor that the efficiency is decreased in order to maintain the same concentration of product. Secondly, in the reactor system, comparison of cascades on the basis of power consumption alone is misleading since to increase the flow from 0.5 to 1.0 gpm at a pressure drop of about 50 psi would be much easier than increasing the pressure from 50 to 100 psi at a flow of 0.5 gpm. Essentially this is to say that arrangements which use cascade to the underflow are superior to those employing cascade to the overflow because the former arrangement might make better use of the available centrifugal pumps to drive the first stage, which consumes about 90% of the power used by the cascade.

Another practical consideration is the lower limit to the size of liquid cyclones. At present, the lowest capacity attainable seems to be about 0.15 gpm. This is too large for the last stage in underflow cascades such as (4) when used in most of the reactor applications. In this case, an arrangement like (9), which terminates in a cascade to overflow, with build-up recycle, using the smallest practical size cyclone, is the best alternative.

The foregoing discussion was based upon the assumption that the efficiencies of all stages in the cascades had the same efficiency, or that the material being separated was of uniform particle size. In the reactor system, the particles will not be uniform, but will follow some distribution curve. In order to arrive at the actual efficiency of a cyclone or a combination of cyclones, this distribution of particles must be considered. In Figure 7, the curve E (D) represents a typical plot of efficiency of particle removal to the underflow against the particle size D. If W (D) were the distribution of particles (the weight percent of particles in a unit diameter increment), then the actual percent separation of the unit cyclone would be given by the integral of the product of these relations over the entire particle size range. In order to obtain the percent separation of a combination of cyclones, the curve E (D) must be used with the appropriate curve of combination efficiency versus unit cyclone efficiency to arrive at a curve for combination efficiency as a function of particle size. This could then be used to integrate over the distribution of particles in the same manner used for a single cyclone.

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$$W(D)$$
$$\frac{dW}{dD}$$

[Faint, illegible markings]

It should be pointed out that the particle size distribution in the reactor will be affected by the presence of the cyclones in the system, since there will be a tendency for the smaller particles to accumulate.

There are three conceivable possibilities which could prevent the successful application of liquid cyclones. The corrosion and erosion encountered might be too large to assure any reasonable life to the units. This can only be resolved by a suitable material of construction. The solids precipitated from the reactor solutions might be of such a size that the cyclones would not be effective. If the fission products are smaller than about 0.3 or 0.4 μ , and cannot be made to grow, the best obtainable data indicate that cyclones will not work.

Finally, the cyclones, because they are necessarily of small diameter, and have small openings, will be very susceptible to plugging. This can be prevented only by removing the large particles before the process stream arrives at the cyclone. This might be achieved by placing a larger diameter cyclone before the cascade. The problem should be carefully studied before using a cyclone cascade in a reactor system.

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