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EFFECTS OF SOLVENT-EXTRACTION CONTACTOR SELECTION ON FLOWSHEET AND FACILITY DESIGN*

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EFFECTS OF SOLVENT EXTRACTION CONTACTOR SELECTION ON FLOWSHEET AND FACILITY DESIGN

Because there are choices, the selection of the best solvent extraction contactor is important. To ask what impact the selection of a contactor would have on the reprocessing plant is the first level of recognition of the complexity of the problem. Were the plant established, the selection of a contactor would be easy. Certainly if a plant were designed around a particular contactor, that contactor would be best for that plant. The fact is that solvent extraction is only one operation among many in the plant, and while it is the primary method of separating and decontaminating material, it is not the largest, nor most complicated, nor most difficult to control, nor most expensive of the operations. The plant is comprised of many systems, embodies many facets, and its design responds to many considerations. To consider the least intangible factors (although perhaps not the most important from a global aspect) which contactor selection affects and which affect contactor selection, the following might be enumerated:

1. The chemical processes used.
2. Design and performance of other plant components.
3. The process control philosophy used.
4. The maintenance philosophy used.
5. Plant layout (for shielding, access, etc.).

There is strong incentive to make this set consistent and compatible. If any operation in the plant imposes unusual requirements on the set,

or fails to appropriately utilize available facilities, a deviation from the optimal is expected.

There would be no incentive, for instance, to reduce the size of a solvent extraction contactor greatly if the majority of components in the plant were expansive and the plant designed to accommodate them.

We will consider three types of contactors here: mixer-settlers, pulsed columns, and centrifugal contactors. We will temporarily ignore the fact that there are good and bad designs for each of these types and that other types exist for which indignant champions can be found. The most important characteristic of these will be summarized for discussion in Table 1.

We are now prepared to discuss how the attributes of these contactors interact with the attributes of the plant in general. Historically, nuclear fuel reprocessing plants have held a very conservative philosophy in all things. Only those processes that could operate within wide error bands were considered. Flow rates were rarely measured and usually controlled within no better than several percent. Process measurements were restricted to density, temperature, and level. Control analyses were routinely reported hours after samples were taken. Under these conditions, it is impossible to use more than three or four stages in an extraction section, one or two stages of scrub, and about six stages of strip in any solvent extraction cycle. The penalty for this is somewhat larger flows throughout the system, larger evaporators, larger chemical use, and a loss in decontamination factor. History testified that these penalties have

Table 1. Summary of important characteristics of contactor types

	Mixer-Settler
+	Proven performance.
+	Easily operated.
+	Provides adequate stages in a positive manner.
-	Uses motors or mechanical drive. Maintenance is simple but required.
-	Large process inventory. Slow response time. High solvent degradation.
-	Large space requirement.
+	Low head requirement.
	Pulsed Columns
+	Proven performance.
+	Simple construction.
+	High reliability.
+	Low maintenance.
-	Limited equivalent stages available for separation.
-	Large height requirement.
-	Fairly high process inventory. Slow response time.
-	Axial dispersion limits performance.
	Centrifugal Contactor
+	Provides adequate stages in a positive manner. Additional stages are cheap.
+	Small process inventory. Rapid response.
-	Unproven reliability.
-	Maintenance simple, but required.
+	Small space requirements.
-	Uncertain chemical kinetic effects.

+ An advantageous characteristic.

- A disadvantageous characteristic.

not been unacceptable, and the processing plants have met the requirements of the time.

We need not speculate on the comparison of mixer-settlers with pulsed columns in these plants because there is plant experience available. Mixer-settlers have been successfully used only where the radioactivity levels were moderate, or where the plant layout restricted the available head room, or where work was done on a very small scale. The large mixer-settlers that were operated at Savannah River, even at the moderate activity levels encountered in processing fuel from production reactors, demonstrated solvent damage sufficient to impede operation. The first cycle mixer-settlers have been replaced with centrifugal contactors.

The issue has then been reduced to a comparison of pulsed columns with centrifugal contactors.

Flowsheet Impact

The chemical processes (or flowsheets) appropriate to the two machines are different. Centrifugal contactors appear to have the potential not only to improve the implementation of conventional flowsheets, but to permit operation of solvent extraction flowsheets that are new in principle. The availability of a large number of stages that operate responsively and without excessive solvent inventory or solvent degradation can change solvent extraction from an operation characterized by the manipulation of chemistry to more nearly a conventional separations cascade. In classical Purex, minimum separation factors of 5 to 10 are provided, whereas, in distillation, the most familiar of the conventional cascades, separation factors

of 1.5 to 2 are considered typical and adequate for making any desired separation. The practicality of actually using separation factors of this lower magnitude in solvent extraction may greatly increase the range of attractive flowsheets. In order for solvent extraction to realize this potential, it is necessary to also provide much better process control than has been found in reprocessing plants. This will be discussed later.

The significance of these new horizons has not been adequately assessed. Conventional flowsheets work and will probably meet most of the needs of new processing demands with nominal modification. In order to be accepted, different flowsheets must offer demonstrable advantages which so far, in the eyes of most reviewers, they have not. It is possible to use more stages and better control to increase solvent loading and, hence, decontamination, but whether an order of magnitude is attainable is a matter of conjecture. Working from conventional flowsheets, the reduction of flow rates and inventory may be more than 10% but perhaps not 50%. Improvements of this magnitude are desirable only if they are cheap. More dramatic possibilities include the elimination of an entire cycle of solvent extraction, or the partitioning of uranium and plutonium without a reductant. Either of these may be possible, but studies that would provide definitive answers are yet to be made. Indeed, we do not know at this time what the possibilities are for flowsheet modification that might appropriately exploit the newly offered potential, and we will not know until much more attention has been devoted to its exploration.

Pulsed columns are not without distinct virtues that impact flowsheet selection. The high tolerance of pulsed columns for suspended particulates, which is well documented, eases requirements for clarification of feed. While tests with centrifugal contactors show that the consequence of some particulates in the feed is not as dire as one could imagine, there remains an order of magnitude between the relative tolerance of the two contactors for solids. Pulsed columns also offer an element of flexibility, in that, within a limited range, one may trade capacity for efficiency. The number of equivalent stages developed can usually be increased by reducing the flows to the system and increasing the pulse rate. Conversely, impurities that invade the system changing the surface properties of the liquids can change pulsed column performance in unpredictable ways. Flowsheets in plants using pulsed columns are tailored to use pulsed column characteristics and make allowance for its limitations.

That pulsed columns could provide many stages in a closely controlled system has been implicitly rejected. While this possibility theoretically exists, we have no data to encourage considering stage heights less than 1.5 to 2 ft in extraction and 3 to 4 ft in scrub or stripping, and the use of multiple columns to increase the available stages compromises the inherent simplicity which makes pulsed columns attractive.

Plant Component Impact

The solvent extraction system is inseparable from the rest of the plant. The philosophy which guides the design of the plant will impact the selection of the solvent extraction contactor. If rugged,

over designed components are generally provided and large safety factors are used, any tightly designed high performance component will be out of place. The dissolution, clarification, and feed adjustment steps before the solvent extraction system, as well as the accumulators and evaporators after it, should reflect a common design philosophy. The pulsed column is more appropriate to a rough and ready conservative philosophy, while the centrifugal contactors fit more appropriately in a plant reflecting a higher level of technology.

Process Control Impact

The adequacy of traditional control methods to the operation of pulsed columns using conventional flowsheets is well established. While centrifugal contactors can be operated in this conventional mode, the realization of a greater potential for these contactors mandates a better control system. The mechanical operation of a bank of centrifugal contactors requires monitoring each stage for failure and maintaining a predetermined pressure in the interface control chamber of each stage. The motors should probably be driven from a variable frequency generator. These requirements are easily met using available techniques.

For proper control of an advanced multistage system, however, flow rates must be controlled within a few percent by feedback loops using in-line measurements of concentration, density, radioactivity, etc. The exact requirements will depend upon which flowsheet and which scheme of control is used. There have been several attractive

schemes proposed, but these have not yet been evaluated. An obvious example is to use the heavy metal concentration in a stage well into the extraction section to control the organic extractant rate.

The use of a simplified computer model operating in real time to tune the solvent extraction system has also been proposed. While such a system would be an inordinate imposition on plant facilities were it the only one, a plant that supports computer controlled laser cutting for fuel element dissemble or computer controlled remote maintenance devices might well support such a computer controlled solvent extraction system.

Maintenance Philosophy Impact

Pulsed columns were developed to be virtually maintenance free. There are no moving parts in the column itself and valves, pulsers, etc., that are used to support the column are chosen for their reliability. Rarely do corrosion problems or plugging problems occur. The centrifugal contactors, on the other hand, will require maintenance. The high reliability of the motors and the simplicity of the design gives a low probability of failure of a single unit (perhaps more than 10,000 h to failure) and the design provides for very simple change out. The maintenance could be performed with an overhead crane and an impact wrench, but the centrifugal contactor system interfaces better with more sophisticated remote maintenance capabilities.

Impact of Plant Layout

The height of the cells in the reprocessing plant may be influenced more by the choice of contactor than any other impact under consideration.

Even in this regard, however, it should be recognized that there are several operations that utilize the head room for which pulsed columns are blamed in the plants where they are used. Were the head room decreased, modification to these would be necessary. The benefits gained from reducing cell height are significant, including structural cost savings, better crane access, simplified maintenance facilities and better ventilation.

There is a space savings realized by going to centrifugal contactors, but solvent extraction cells are typically dominated by tankage and peripheral and support components. The contactors themselves consume a small fraction of the total space. This observation, however, recalls an earlier assertion that adding more stages to the solvent extraction system when centrifugal contactors are used is done quite cheaply.

Conclusions

In the above discussion it was attempted to develop the notion that the selection of a solvent extraction contactor is part of a more general development of principles and philosophy guiding the overall plant design. Specifically, the requirements and constraints placed on the plant by the solvent extraction system must be consistent with those imposed by the other operations, which generally are more expensive and more complicated. Were a conservative philosophy employed throughout the plant, the choice of pulsed columns seem correct. Were the plant intended to employ modern techniques and state-of-the-art technology, particularly in remote maintenance and process control, the selection of centrifugal contactors seems appropriate.

The process improvements attainable from employing more stages in a more tightly controlled solvent extraction system seem marginal at present when applied to conventional flowsheets, although the cost-benefit may be attractive in a modern plant. The potential for improvement through major flowsheet modification can not presently be assessed quantitatively, since it necessarily depends on innovation in the exploitation of a tool which has not heretofore been available.