Hydrogenation

Practical aspects of converter design, heat recovery and catalyst separation

Factors in choosing what type of hydrogenation system to use are discussed in this paper by Ken Carlson of Johnson-Loft Engineers Inc., one of JAOCS' *associate editors for news.*

Hydrogenation probably is the most researched and discussed process in the fats and oils industry. The many interacting requirements and effects of process design and conditions, catalyst quality, feedstock and product specifications create a complex puzzle that can be solved in many ways.

Much material has been presented and published on the academics of the process and the function and use of catalysts. Information about proprietary commercial plant designs also has been published and is available from almost all the major process and equipment suppliers of the industry.

Batch processing still the norm

Most commercial operations require frequent stock changes or alterations in the processing parameters which are difficult to handle in continuous systems. For this reason, batch hydrogenation is the preferred method unless very large runs of one and the same product are to be processed. This article, therefore, will discuss only batch type operations.

Most commercial batch designs operate with the use of "dead-end" or "loop" reactors (converters), as illustrated in Figure 1, followed by some form of catalyst separation system. A couple of typical systems are shown in Figures 2 and 3.

The first is a basic system with minimum equipment suitable for small plants with low turnover requirements. It operates without the aid of external heat exchangers and heat recovery. Bulk catalyst removal and scavenging are done in one filter through recirculation to the converter.

The system in Figure 3 is a complex system at the other end of the scale, suitable for large plants, and is equipped with two converters with evaporative cooling as well as feed and drop tanks for optimum equipment utilization and heat recovery. Catalyst removal is done in two steps with trace catalyst removal in a separate filter.

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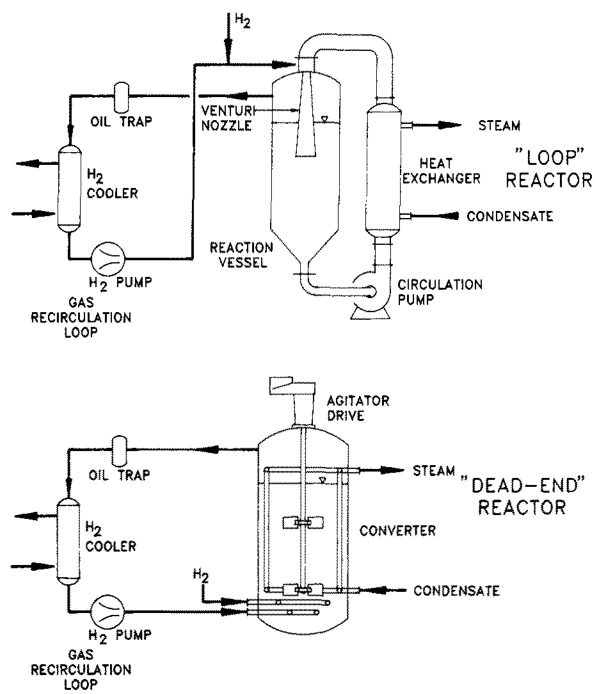

FIG. 1. Reactor types for hydrogenation.

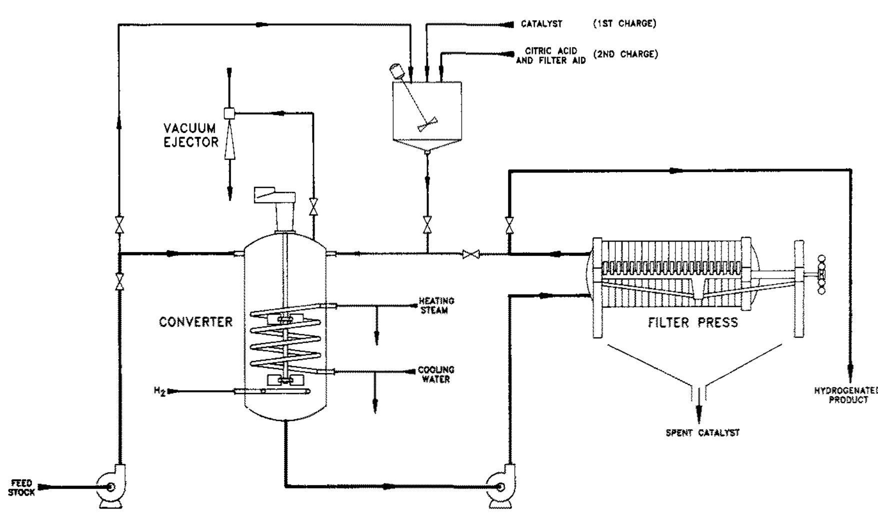

FIG. 2. Basic hydrogenation system.

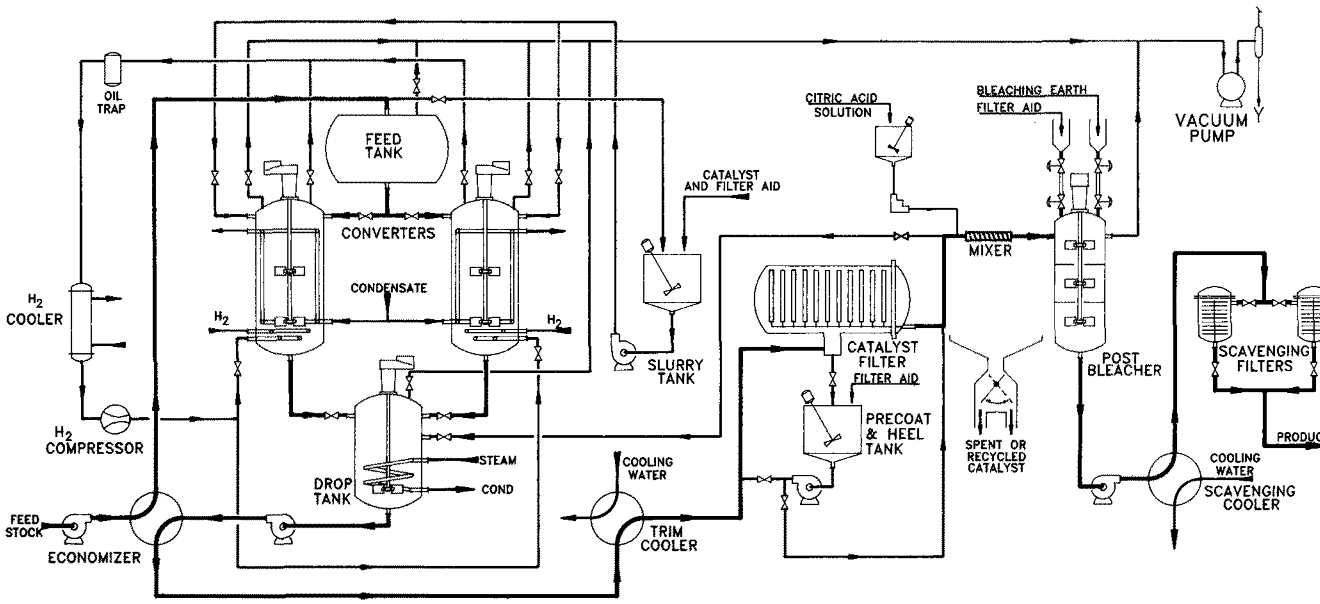

FIG. 3. High capacity hydrogenation system.

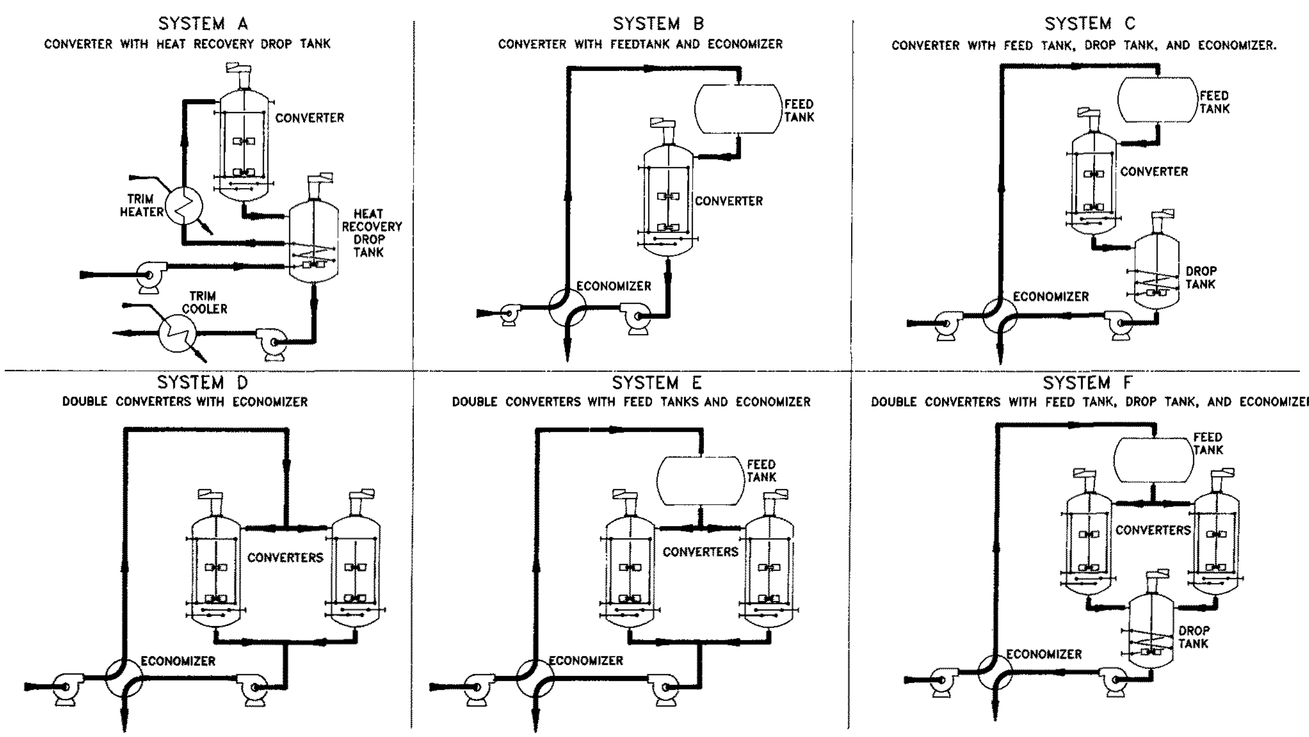

FIG. 4. Design options for heat recovery and equipment utilization.

The systems show so-called "dead-end" reactors but could also be shown in a similar fashion with "loop" reactors.

"Loop" or "dead-end" reactor?

The main objectives when designing a converter are, on one hand, to minimize the required reaction time as well as the use of hydrogen and catalyst by providing good distribution and mixing. On the other hand, the mixing techniques must not complicate selective hydrogenation when this is required.

These two objectives are hard to combine since selectivity can be reduced by intense agitation.

The "loop" design has a higher potential for close and rapid contacting between oil, gas and catalyst. The possible reduction in catalyst consumption and reaction time however, should be weighed against the risk of more difficult conditions for ensuring repeatable selectivity. Furthermore, the energy and maintenance requirement of the "loop" circulation pump should be compared to those of the "dead-end" turbine drive.

The less intense agitation of the "dead-end" design should be more forgiving and predictable for practicing selective hydrogenation. Furthermore, in this type of operation, catalyst consumption is relatively low, and rapid reaction rates are not a major requirement, thus reducing the potential operating cost advantage of the "loop" system.

Gas recirculation can be added to both designs to reduce gas lost from venting. This is especially effective for the "dead-end" converter. It also removes moisture when converters are maintained under hydrogen pressure between batches.

Temperature control and heat recovery

The exothermic reaction of the process produces energy equivalent to a temperature increase of the oil of up to 1.7°C per unit drop in iodine value (I.V.). The total I.V. drop ranges from as low as five units for "brush" hydrogenation, to more than 120 when, for example, making stearine. Feedstock is usually preheated to 120–170°C before beginning the reaction. This means that the end temperature can be over 200°C depending on if and at what point the reaction is controlled (cooled).

Usually the temperature is controlled at some point during the reaction so that considerable amounts of energy are absorbed by the cooling system. The energy traditionally is removed by cooling water and thus becomes a utility cost. Furthermore, unwanted steam flashing and "water hammers" may occur when the water feed is shut off. If condensate instead is purposely flashed as low pressure steam and, for instance, used to heat boiler feed water, this problem is avoided and energy is recovered instead of spent.

Basic system operation

A system as shown in Figure 2 employs the coil in the converter to both heat and cool the batch. Heating to starting temperature normally is allowed to take up to an hour. This usually means that cooling to filtration temperature will take less than 45 minutes. The charging of the converter can take at least 10 minutes while discharging is governed by the filtration rate which, for economic reasons (sizing of the filter), will take about an hour.

This all means that the cycle (turnover) time for a basic system will be about three hours plus the time the oil is in the converter. This time can be as low as 40 minutes but is more often scheduled for a full hour for practical reasons. Under these conditions, the basic system will turn over in four hours which makes six batches per day. When processing impure and slow reacting products, however, the converter time may very well be more than three hours, cutting the production down to three batches per day or less.

Holding vessels and external oil-to-oil heat recovery

Oil-to-oil heat recovery in batch systems can be accomplished in a separate agitated drop tank (or compartment) that is equipped with a heat recovery coil as shown in Figure 4A. The feedstock is charged to the converter through the coil, thereby picking up some heat and precooling the hydrogenated batch. The introduction of spiral heat exchangers, however, has made other heat recovery designs more attractive. An external economizer enables charging the converter and discharging the drop tank simultaneously, thereby increasing the heat recovery which also shortens the turnover time. This, in turn, generally means that the drop tank can be replaced by a feed tank which eliminates the need to keep

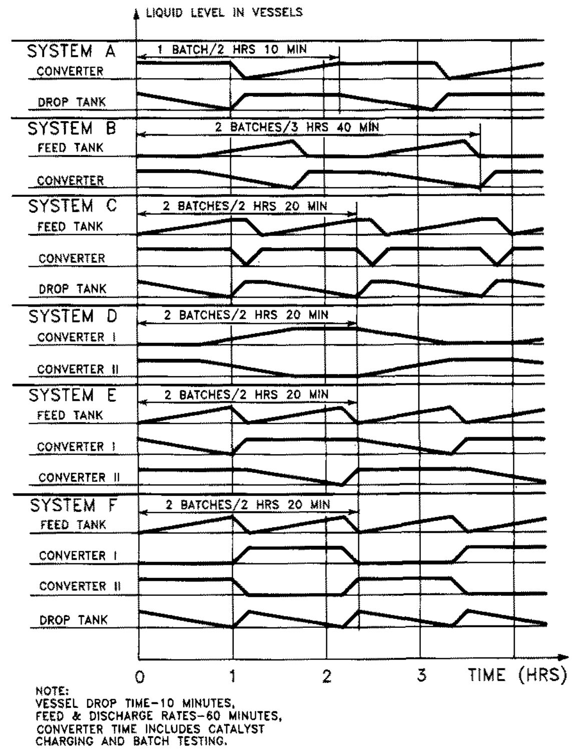

FIG. 5. Cycle times with 40 minutes converter time.

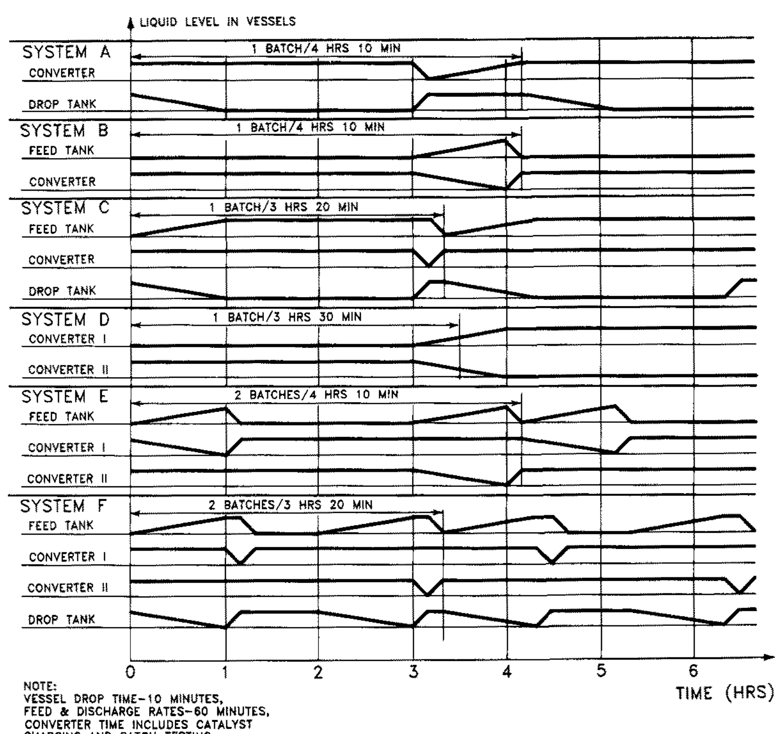

FIG. 6. Cycle times with 3 hours converter time.

TABLE 1

Characteristics of Different Hydrogenation Systems*

	40 Minutes converter time						3 Hours converter time					
	A	B	C	D	E	F	A	B	C	D	E	F
Turnover (hrs:mins)	2:10	1:50	1:10	1:10	1:10	1:10	4:10	4:10	3:20	3:30	2:05	1:40
Batches per 24 hrs	11.1	13.1	20.6	20.6	20.6	20.6	5.8	5.8	7.2	6.9	11.5	14.4
Batch size (MT)	18.0	15.2	9.7	9.7	9.7	9.7	34.5	34.5	27.8	29	17.4	13.9
Rel. efficiency %	31	36	57	57	57	57	72	72	90	86	144	180
Investment K$**	+55	0	−60	−35	−5	+25	+300	+255	+215	+340	+170	+130

*As illustrated in Figure 4.
**As compared to B"40".

TABLE 2

Characteristics of Different Catalyst Filter Types

	Pressure leaf tank filter	Open discharge manual P&F filter	Closed discharge automated chamber filter
+	-Easy cake discharge	-No heel & related equipment	-No heel & related equipment
+	-Inexpensive	-Forgiving to flow fluctuation	-Forgiving to flow fluctuation
+	-Low residual oil in cake	-Low residual catalyst in oil	-Low residual catalyst in oil
+	-High capacity	-Simple design	-Low labor
−	-Heel & related equipment	-Messy and labor intensive cake removal	-Expensive
−	-Requires precoat	-Requires paper dressing	-Mechanically complicated (compared to manual press)
−	-Requires circulation during feed interruptions	-Exposes oil to air	

the catalyst in suspension with an agitator. A feed tank also can be installed on the ground floor by adding a high capacity charge pump; this will add about 10 minutes to the turnover time.

There are several design options available for heat recovery systems depending mainly on the size of the plant, required reaction time, investment cost and complexity of operation.

Six typical systems are illustrated in Figure 4, ranging from the single converter, with heat recovery drop tank, to double converters with heat economizer and both feed and drop tanks.

Two examples can be used to compare the difference in performance of the systems.

A capacity of 200 metric tons per 24 hours (TPD) is selected and the systems are assumed to operate with either 40 minutes or three hours converter time. Under these conditions, the operating schedules for the various systems will be as shown in Figures 5 and 6.

A key issue is the relative difference in investment cost for the various designs. With the "40 minute" B system serving as a reference with the base cost zero, the difference in investment for each of the other systems can be estimated in U.S. dollars. Table 1 summarizes the major characteristics of the systems including the relative difference in investment. From this it appears that Systems C and D offer the best solution for a plant requiring only short converter times and no plans for future capacity increase. Both have a relatively lower investment cost thanks to the smaller converters and related equipment, such as filters, etc.

On the other hand, they do not perform well when used for long converter times. For this purpose either an additional converter or a feed tank must be added. System C, modified to type F, with an