IMPORTANCE OF RECIRCULATION IN EVAPORATORS

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Reading the discussion of evaporator design, I had a feeling that the subject still remained open because the authors have not convinced the readers enough for either one of the two systems in question, open or sealed downtake.

The phenomena of evaporation in vertical tubes has been intensively studied throughout the world and some of the results concerning the sugar industry are as follows (6):

1. There is an optimum liquid level (static pressure at the bottom of the tube) which gives the highest value for heat transfer rate. The level is expressed as a percent value of the total tube length and depends on the specific gravity of the liquid in question. For sugar factories the level value varies from about 33% (first body) to 70% (last body).

1a. That optimum level gives also the minimum color increase.

2. Velocity of the liquid entering the tube(s) at the bottom end is the critical value. The heat transfer rate increases with increased velocity and has the highest value at the inlet velocity of 5 to 7 feet per second.

3. The heat transfer rate under the conditions of nuclear boiling depends on vapor-liquid ratio. It increases with an increase in vapor rate from 70% to 98% but further increase leads to the very sharp drop of the heat transfer rate.

4. A frequent change of flow, level density and heat load is a cause of an intensified scaling of the evaporator tubes.

5. The liquid (juice) density influences the heat transfer - the lighter the juice the better heat transfer. Most of the authors use the density of outgoing juice as a factor affecting heat transfer rate.

There are many other factors affecting the efficiency of an evaporator but in further discussion we will presume that they were equal in all cases.

The juice in an evaporator is carried up a tube by expanding vapors. The same effect is employed by "air-lift" pumps where expanding air bubbles act as pistons pushing the liquid up. Efficiency of air-lift pumps is considered low for an imperfect sealing allows the liquid to slip back around the bubbles; about ten volumes of air are necessary to lift one volume of liquid. Assuming that, and the fact that by evaporating one volume of water we produce about one thousand volumes of vapor, we could find the potential capacity of the "vapor-lift" in an evaporator. If we have one hundred units of juice entering an evaporator and we evaporate thirty units of water, then the "vapor-lift" could lift about three thousand liquid units!

In the case of a single-pass evaporator juice supply to the tubes corresponds to the normal juice flow and obviously is about thirty times smaller than the potential lifting capacity of the evaporator. To compensate for that imbalance the "vapor-lift" has to decrease the efficiency and, in reality, it is achieved by lowering the juice level. The establishment of the level happens to be "self-adjustable" and depends on juice flow, evaporation rate and specific gravity. For that reason it is not possible to regulate the level, by an outside regulator, in a single-pass evaporator. The juice level, so self-established, is lower than the optimum level required for the best heat transfer rate.

In the case of a single-pass evaporator, vapor produced in the tubes (as in the example above) has a volume of about 30,000 units and the remaining liquid (juice) of about 70 units. Starting from that we could say that the vapor rate in the upper part of the tubes exceeds the optimum value of 98% and therefore the resulting overall heat transfer rate is not as high as possible.

As to the velocity of the juice entering the tubes; in the case of a single-pass evaporator that velocity, in the absence of flashed vapors, has a value of less than one inch per second and it is, obviously, far below the optimum value. Flashing of the incoming juice (if there is any, first body) might increase the fluid volume and the velocity up to ten times.

It is known that the juice density affects heat transfer but there are not any reliable estimates referring to the gradient of the density within the tubes. There is no evidence that, at the same Bx of the juice coming into the body and the same Bx of the juice leaving the tubes (not body), the density of the juice within the tubes is not the same with and without a recirculation. It could be shown by simple mathematical methods that the "average" density within the tubes is higher in case of recirculation but in reality it does not have to be so. One sure thing is that the difference between the Bx of the juice incoming to the tubes and the Bx of the juice outcoming (off) the tubes is the greatest in the case of the single-pass construction. It is disputable whether that is an advantage or disadvantage.

Comparing the retention times, at the same dimensions of the evaporators, same juice flow and same rate of evaporation, there will be no significant difference whether the downtake is sealed or open. Assuming that, I could not agree with the statement (3) that "if the average rate of recirculation is three, then the average retention time would also be three." Considering the same average retention time it is obvious that the juice is longer in contact with the heating surface in case of the single-pass, than with recirculation. That is because in the case of the single-pass the contact time is the same at the retention time, but in the case of recirculation the juice spends one part of the retention time outside the tubes.

Correctly speaking, the temperature as measured always represents a statistical average of differently energized molecules and there are always some of them over, and some of them under, the average level. The color formation is a molecular reaction; destruction of normal juice constituents and formation of "colored" molecules under the influence of high temperatures. Generally speaking, if a molecule is formed (or destroyed) once it could not be formed (or destroyed) again. A strong turbulent mixing (recirculation) helps in leveling off – reduces extremes and increases the number of average energized molecules. With respect to this we could say that a recirculation would not stimulate the color formation but would do just the opposite for, the juice would have less time in a direct contact with the heating surface and the number of over-excited molecules would be decreased.

The resulting summary from the foregoing discussion could be as follows:

1. The single-pass evaporator cannot maintain the juice level at the optimum value. The self-established level is somewhat lower than the optimum one, but is maintained fairly constant.

2. The velocity of the juice entering a single-pass evaporator is far below the optimum velocity and cannot be improved.

3. The rate vapor/liquid (within the tubes) in the case of a single-pass evaporator is too high and contributes to a decreased heat transfer rate.

4. The pattern of the juice density within the tubes and its influence on the heat transfer in either case is not quite clear.

5. The longer contact time between the juice and the heating surface in a single-pass evaporator might be a source of intensified color formation, and, possibly scaling.

A well designed evaporator using recirculation could overcome the above mentioned defficiencies, i.e. the level could be adjusted at any desirable value, the velocity of the juice entering the tubes could be significantly increased, the vapor/liquid rate could be adjusted, the liquid flowing through the tubes is of more uniform composition and in shorter contact with the heating surface.

In spite of the conclusions just made, the efficiency of some of the evaporators with open downtake has been improved after the sealing of the downtake (1,5) i.e. changing the system from one with a recirculation to the single-pass. One of the reasons is that, in a case as presented on page 23, Sugar Journal, August 1969, the juice leaving the body has lower density than the juice leaving the tubes (2). In that case the portion of the juice passing through the tubes has to reach a higher density than in the case of the single-pass. Working so, at a higher rate of concentration (2) than necessary the heat transfer is affected and scaling, due to the concentration, is favored. Another important factor is the juice level. It is likely that the level in an old vessel could have any value, generally speaking, and might have been frequently changed upon the operator's decision. That frequent change of the operating level resulted in the lower overall heat transfer rate and intensified scaling. The importance of the velocity of the juice entering the tubes and the influence of the flash-vapors has been mentioned. The old construction of the evaporator, as has been presented, allows a portion of the flash-vapors to escape through the downtake thus decreasing velocity of the liquid entering the tubes.

By sealing the downtake the performance was improved (constant level, lower Bx and full utilization of the flash-vapor) but it should not be considered as an advantage of the sealed downtake but as a failure in the construction and operation of an open downtake evaporator.

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