Thoughts on Refinery Boiling Schemes.

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1. Introduction

This paper is based upon observations of white sugar boiling schemes in a number of refineries and some consideration of the underlying factors affecting the mass balance of the schemes.

While many refineries have been constructed to use a traditional sequence of strikes or boilings to produce white sugar, there are several smaller refineries operating with single white strike boiling schemes. Other refineries using continuous pans or vacuum crystallisers have adapted their boiling schemes to suit these particular processes.

Our intention is to stimulate thought and discussion as to what is the right boiling scheme for a particular situation, and to consider the best place within that scheme for decolourisation processes such as granular activated carbon. We will probably raise more questions than answers, particularly in areas where published information is scarce.

2. Series Boiling Scheme

Table 1 below shows a typical simplified 4 boiling mass balance based on 50% yield of dry solids at each stage, a colour increase during boiling of 5% and a colour elimination ratio from massecuite to sugar of 10.

4 Boiling Scheme

Yield	50%	
Colour ratio	10	= massecuite colour / sugar colour
Feed colour	200	
Feed purity	99.4	
Colour gain	105%	from pan feed to massecuite

		Massecuite	Sugar		Runoff or jet syrup	
Strike	**Solids in**	**Colour**	**Solids**	**Colour**	**Purity**	**Colour**
R1	100	210	50	21	98.8	399
R2	50	419	25	42	97.6	796
R3	25	836	12.5	84	95.2	1588
R4	12.5	1667	6.25	167	90.4	3168
Blended sugar output			93.75	44.6		

Table 1. Traditional 4 Boiling Mass Balance

This analysis shows that the 4th boiling R4 sugar is less than 7% of the blended sugar mass, but yet R4 as with the other sugars each contribute 25% of the colour mass present in the product. Without the R4 sugar the product colour drops to 36 ICUMSA and the R4 sugar would then be melted back into the fine liquor, helping to reduce the colour fed to the R1 pans.

3. Colour Elimination Factors

Table 1 starts from 200 ICUMSA fine liquor and the calculations show sugar that is only just under the 45 ICUMSA requirement for EC2 sugar. This is contrary to the work published by Lionnet[1], who presents a mass balance that achieves 40 ICUMSA product sugar from fine liquor of 387 ICUMSA. This discrepancy arises in the main because the colour elimination factor reported by Lionnet is substantially greater than 10 and furthermore it increases with increasing massecuite colour.

The standard simplification of using a ratio of 10 is clearly not supported by practical experience. In SIT paper #773 Moodley[2] reports that the affined white sugar crystal colour can be derived from the feed liquor colour used to boil it by the following equation :

Crystal colour = 0,76 + 0.0168 * feed liquor colour

This result was derived from laboratory experiments with liquor in the range 150 to 1000 ICUMSA, as shown in Figure 1 below. Moodley goes on to use the above relationship on the basis that 80% of the sugar colour is in the crystal which gives colour elimination factors in the range 36 to 45 over the range of feed liquor colours considered. These factors perhaps illustrate the best achievable colour elimination under ideal conditions.

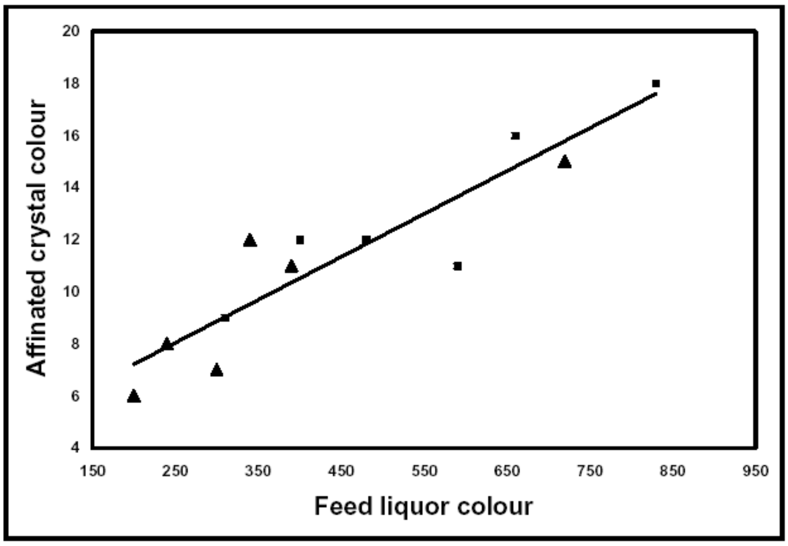

Figure 1. Colour Transfer to Crystal (Moodley)

Vawda (2005) collated results for 4 boiling schemes from 4 refineries, all with carbonatation as their primary process. These results, shown in Figure 2, have average elimination factors of 16 for the first boiling rising to 35 for the 4th boiling, the results fit the following equation :

Colour elimination factor = 15,5 + 0.007 * feed colour (range 300 to 3000 ICUMSA)

Where elimination factor is defined by massecuite colour divided by sugar colour.

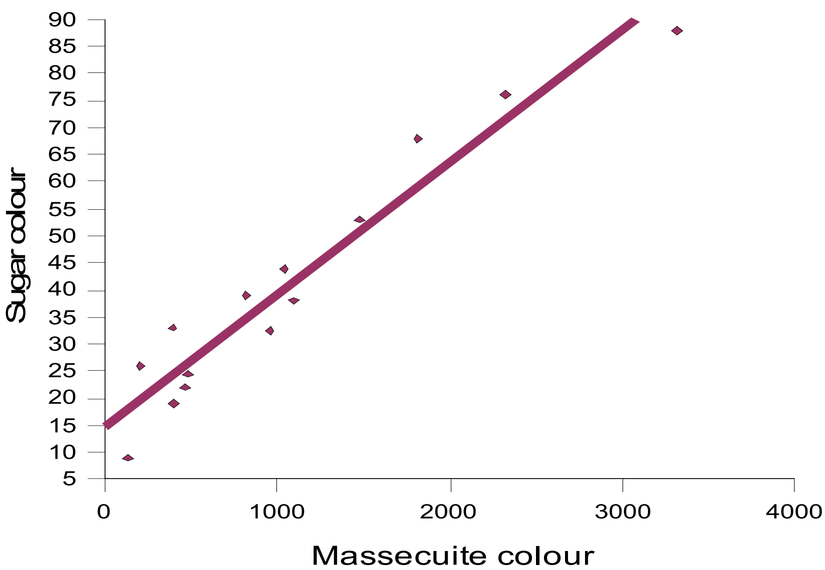

Fig 2. Collated Plant Data for R1-R4 Refined Sugar Strikes

Lionnet reports colour elimination values in the range 17 to 26 for 1st through 4th boilings with massecuite colour rising from 400 to 3100 which are consistent with the above data.

These and other published sources provide a substantial body of evidence that the colour elimination in cane refining white sugar boilings is not 10 but in fact substantially better than 10 and increases with the rise in massecuite colours. Using the above equation to re-work Table 1 gives the following result :

4 Boiling Scheme

Yield	50%	
Colour ratio	15.5 + 0.007 * massecuite colour	
Feed colour	387	
Feed purity	99.4	
Colour gain	105%	from pan feed to massecuite

		Massecuite	**Sugar**		**Runoff or jet syrup**	
Strike	**Solids in**	**Colour**	**Solids**	**Colour**	**Purity**	**Colour**
R1	100	406	50	22	98.8	791
R2	50	830	25	39	97.6	1621
R3	25	1702	12.5	62	95.2	3342
R4	12.5	3510	6.25	88	90.4	6932
Blended sugar output			93.75	36.3		

Table 2. Mass Balance with Increasing Colour Elimination

Comparing Tables 1 and 2 it can be seen that the increased colour elimination factors allowed an increase in fine liquor colour while reducing the colour of the blended sugar. In the case of Table 2 the mass of R4 sugar is the same but its contribution to the mass of colour is reduced to 16% of the total. In this instance removing the R4 sugar from the blend reduces colour from 36 to 33 ICUMSA.

We believe that a colour elimination factor that increases in proportion to the massecuite colour is more representative of industrial practice than a constant elimination. We also believe that the common assumption of a factor of 10 is unrealistically low, at least for the carbonatation-based refineries that were reviewed by the authors above.

Where a colour elimination as low as 10 or less is found in practice this is usually due to under washing in the centrifugal, i.e. using less wash water to increase yield and consequently leaving more mother liquor present on the crystal surface. This can be seen in practice where increasing wash water quantities are used on subsequent strikes, such that only the later (3rd & 4th strikes) are fully washed to the capability of the centrifugal.

Another factor to consider is the process technology in use. Moodley's results included some from ion exchange treated liquor where the affined crystal colour was found to be somewhat greater than that from equivalent sulphitated or carbon treated liquor. This highlights a possible variation in the types of colour removed by different processes leading to different colour elimination factors.

4. Solids Yield

The traditional assumption is that a solids yield of 50% is a reasonable figure for a white sugar boiling. If the massecuite brix is 90 then this suggests a crystal yield from the centrifugal of 45 % on massecuite, which seems a little low as higher figures are routinely achieved in lower purity beet white sugar massecuite.

Crystal content in high purity massecuite tends to be limited by handling characteristics, principally viscosity and the flow rate into the centrifugals. It can be shown that the crystal content is limited to 55 to 60% by the need to have enough mother liquor to fill the gaps between the crystals, plus a small excess to provide fluidity. Above 60% crystal content the massecuite becomes a damp solid rather than a fluid and is very reluctant to flow, even with mechanical assistance.

If we take a crystal content of 57% by mass, the solids yield at a range of massecuite brix values is :

Massecuite brix	88	90	92
Pan solids yield	64.8%	63.3%	62.0%

Table 3. Pan Solids Yield at 57% Crystal by Mass

All of these values are over 60%. If the centrifuge crystal yield is 90% then the corresponding overall solids yield is:

Massecuite brix	88	90	92
Combined yield	58.3%	57.0%	55.8%

Table 4. Combined Yield Pan + Centrifugal

The assumed value of 90% centrifugal crystal yield is not particularly high, especially if the colour elimination allows use of a modest amount of wash water. Centrifugal manufacturers have offered yields of 92.5%, and higher yields have been recorded in plant tests.

To achieve a solids yield of only 50% requires either a very large loss of crystals in the centrifugal, around 80% yield or less based on the above crystal content values, or a poor yield in the vacuum pan that depresses crystal content. With a 90% centrifugal yield the crystal content would have to be 50% to yield 50% on a dry solids basis from a 90 brix massecuite.

We believe a solids yield of at least 55% is appropriate for high purity massecuite, and 60% is probably achievable in the right circumstances. As Table 5 below illustrates, 3 boilings of high yield can give higher total yield than 4 boilings of a lower yield per stage :

	Total white sugar yield	
Solids yield per stage	4 boilings	3 boilings
45%	90.8	83.4
50%	93.8	87.5
55%	95.9	90.9
60%	97.4	93.6

Table 5. Total Yield for 3 & 4 Boilings

The R4 runoff syrup purity is a popular measure of total yield of the white sugar boiling, however it is rather sensitive to the fine liquor purity. For a constant yield the R4 runoff purity can vary by as much as 3 to 5 units for a variation in fine liquor purity of only 0.2 units from 99.4 to 99.6.

5. Single Strike White Sugar Boiling Schemes

Single strike schemes are used in a number of refineries for various different reasons. The primary advantage is a simplification to a single line of equipment making a single grade of white sugar. In some cases the single white strike is associated with the boiling of yellow or soft sugar from the resulting runoff liquor, which makes the purity of that material less critical.

5.1 Russian Scheme.

Russia is the world's largest importer of raw sugar and refines the majority of this sugar using a single white sugar strike system. A total of three boilings are used, the white strike and a two stage recovery process typically yielding molasses around 50 purity after cooling crystallisation.

A 3 boiling scheme is used in Russia because the raw sugar is refined in beet factories designed and constructed with such a scheme. The refining process has been adapted to suit the available systems, rather than modifying the systems for refining. As a result we have an interesting case study with a different approach. Carbonatation is used with SO_2 addition to the filtered liquor but no secondary decolourisation processes (activated carbon, ion exchange) are in widespread use.

To maintain a good recovery of sugar the purity of the 2nd boiling is held in the low to mid 80s. The quantity of 2nd and 3rd massecuite is then quite small, particularly in the typical refinery processing 600 to 800 tonnes of raw sugar per day. The quantity of 1st (white) massecuite is determined by the yield of the strike, with runoff syrup from the 1st boiling recycled both to carbonatation and to the 1st product pans.

The recycle takes two forms – the "green syrup" that is primarily mother liquor, and the "wash syrup" that consists of some mother liquor together with washings from the sugar and from the basket cleaning. The lower purity green syrup is recycled back to the carbonatation where it mixes with the melted raw sugar. The effect of this is to depress the purity of the carbonatation from the 98 or higher purity melt to around 92 purity to feed the white sugar pans. By holding down the purity of the white strike the runoff or green syrup purity is held below 85 and the "recovery" 2nd and 3rd boilings have a consequently small throughput and low purity.

Valves on the centrifugal divert the runoff according to a timer, and this timer can be adjusted to change the proportions passing to green and wash. In effect the timer becomes a purity controller for the white sugar boiling. An advantage of recycling around carbonatation is that there is the opportunity to adsorb colour from the recycled syrup each time it passes through the system, so the primary decolourisation and defecation processes of carbonatation are repeatedly applied to the recirculating liquor stream.

This recycling through carbonatation allows production of white sugar with 50 to 80 ICUMSA from raws of over 2000 ICUMSA without affination and without a secondary decolourising step based on adsorption. A simplified diagram of the Russian scheme is shown over in Figure 3.

The disadvantage is that the consumption of lime is usually quite high – around 4% CaO on raw sugar – and the flow rates through the carbonatation and filtration stages is inevitably much higher than it would be on a "once through" system. It is not clear if the lime consumption is high of necessity, or if it is in part due to the use of an oversized lime kiln with limited turndown capability.

The high recycle flow through the carbs would justify a higher lime consumption than a standard refinery carbonatation scheme, but not as high as 4% on raw sugar.

The colour elimination factor in the white sugar strike is around 30, based on the Stammer measurement. This is within the range reported elsewhere and suggests a massecuite colour of 1500 to 2400 ICUMSA.

There is scope to make improvements to reduce its lime and steam consumption and to reduce sugar colour, as the market requires it.

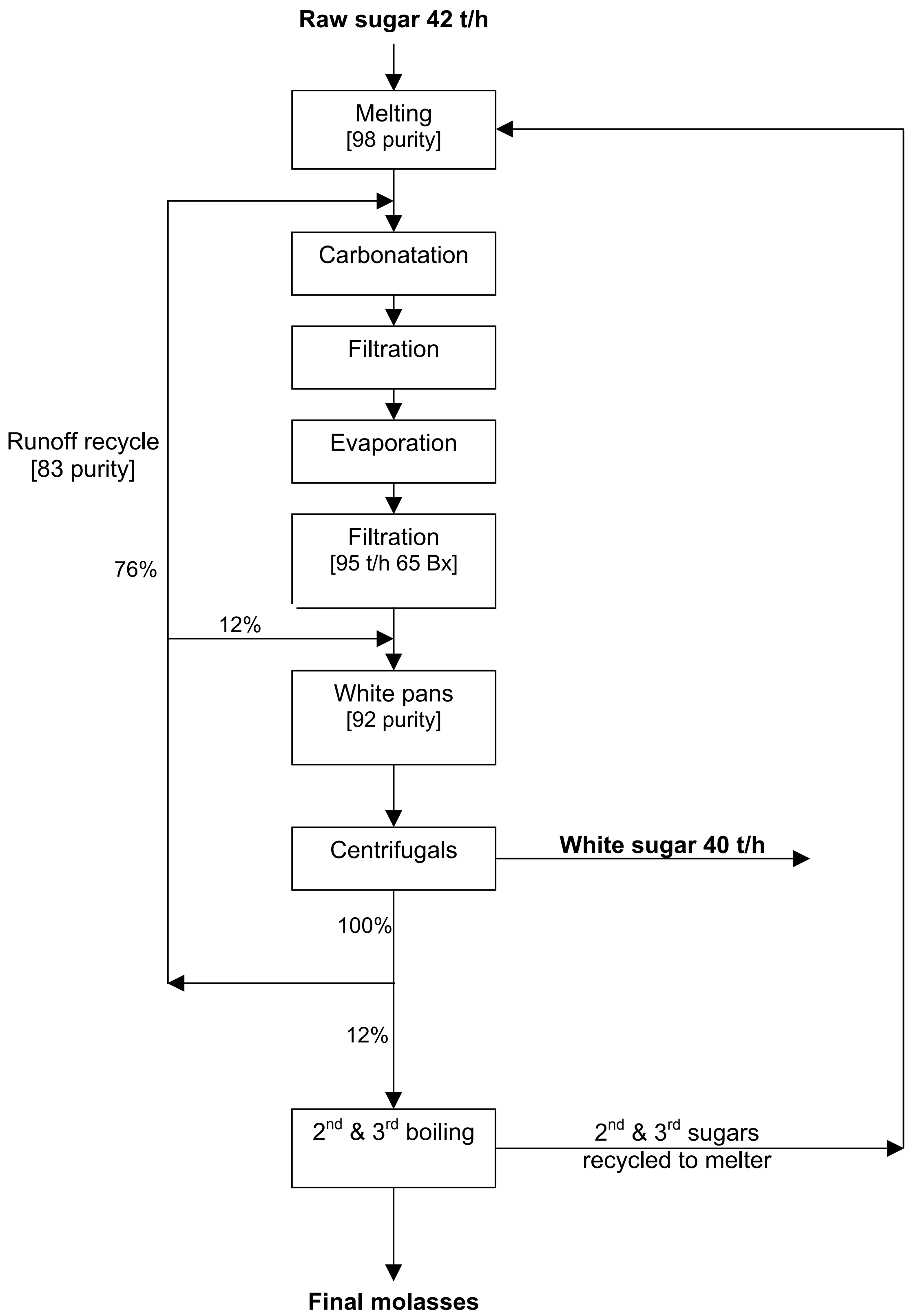

Figure 3 Simplified Flows in Russian Refinery Boiling Scheme

5.2 Other Single White Boiling Schemes

The single white sugar strike systems favoured in Portugal and Canada have been described in previous SIT papers and are briefly mentioned by Chou[4]. The recycle of runoff syrup is either separately to the pan in the so-called "back boiling" approach, or returned to mix with the fine liquor in an "in boiling" scheme. Control can be either by continuous blowdown or by recycling 100% until either the runoff colour or the sugar colour reaches a preset limit, at which point the runoff is rejected to the next stage. The continuous approach should give a more stable product quality.

Typically the runoff is reported to reach colours of 4000 to 6000 ICUMSA, which implies a massecuite colour of 2000 to 3000 ICUMSA. As these schemes are producing sugar of up to 60 ICUMSA there is an implication that the colour elimination factor in a recycling scheme is perhaps as high as 50 in the later stages of a boiling cycle, prior to rejection of the runoff.

5.3 Continous pans

Continuous vacuum pans are large capacity units which are a good match for recycling schemes. The VKT installation at Al Khaleej is reported in SIT paper #751 as using a large recycle of R1 runoff back to the R1 VKT. Later evolutions of that boiling scheme recycle R2-R4 sugar to seed the VKT and the syrup recycle is no longer necessary as an additional VKT is employed on R2 duty.

Continuous Vacuum Crystallisers (CVCs) are employed in some refineries, these increase the yield of a boiling stage by 20 to 30% by taking runoff syrup back to mix with massecuite in a flash cooling crystalliser as shown in Figure 4 below. The runoff provides both the diluting medium to control viscosity and the sugar required to feed the crystal growth. The very high stage yield that results from this system means that fewer white sugar boilings are necessary for a given overall yield.

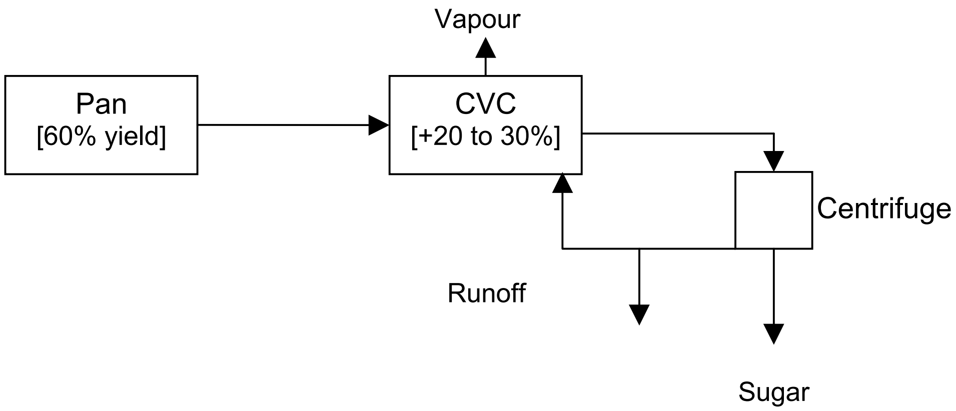

Figure 4 CVC Schematic

5.4 Simulation of a single strike white sugar scheme.

Using Sugars™ software the performance of a recycling single strike scheme can easily be simulated. The potentially difficult iterative calculations are handled automatically and the unit operations models for pans and centrifugals include solubility and colour increase factors. The results are shown over in Figure 5.

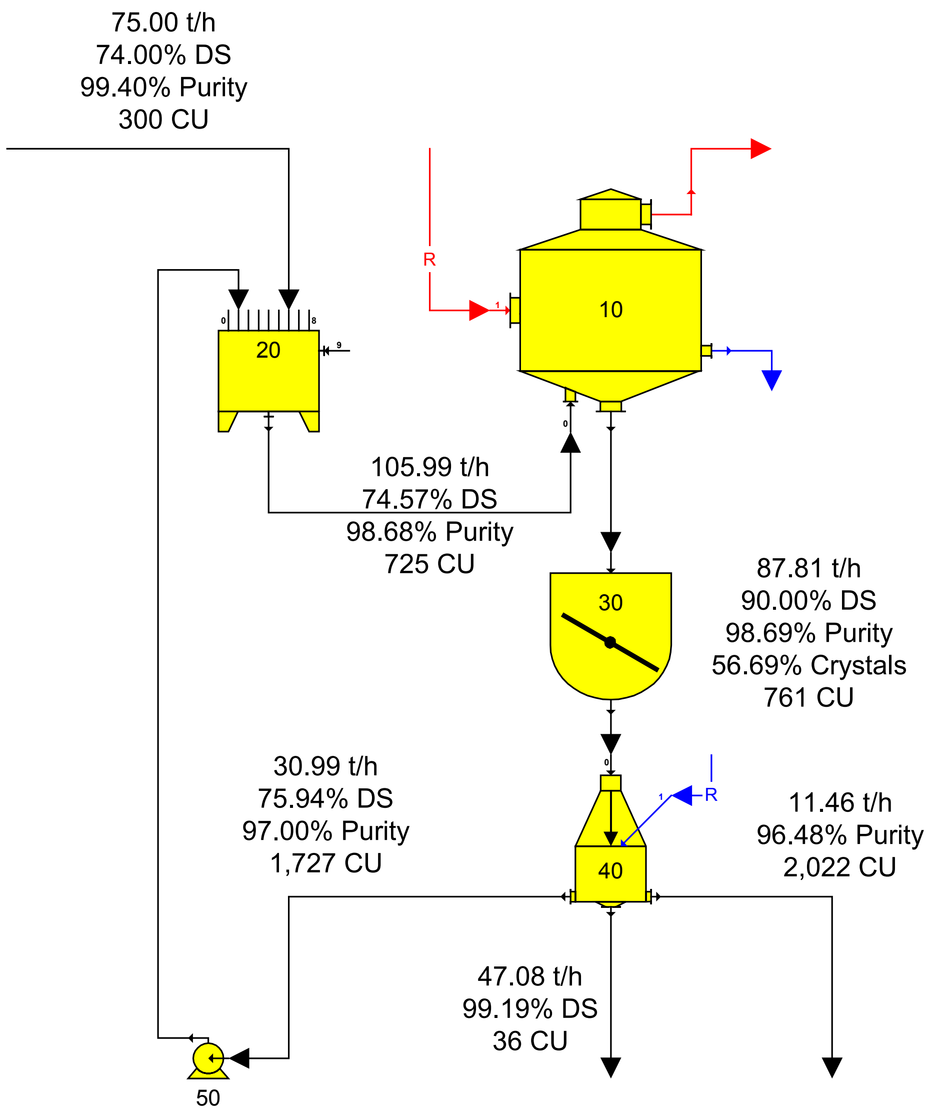

Figure 5 Single white strike mass balance

The above balance shows a solids yield of 59.1% over the pan and centrifugal combined, with the crystal loss in the centrifugal set at 7.5%. The overall solids yield of the station including the recycling is 84.2% which is about 3 percentage points less than a 3 strike boiling scheme with a solids yield of 50% per stage. In other words a recycling strike can be equivalent to nearly three strikes in series with the advantages of making a single grade of sugar.

If the fine liquor colour can be reduced or if the colour elimination factor is higher, then the recycle can be increased and the overall solids yield of the station will be further increased. As an example, reducing the feed colour from 300 to 200 ICUMSA allows the reject runoff purity to fall from 96.5 to 95.0 by recycling more, making an extra 2.8 t/h of sugar as a result. The overall yield rises from 84.2% to 89.2% which is half way between the yield of a 3 and a 4 strike series boiling scheme.

In the above example 70% of the dry solids in the pan are from fresh fine liquor and 30% from recycled runoff. In practice we would recommend using separate tanks for the two pan feed materials and adding the runoff in the later part of the pan cycle. This will help to minimise the residence time of the runoff part as it will stay in the pan the shortest time and part of it will be bled off to discard by the centrifugal separator valves.

There may be some advantage to sugar colour in seeding the pan with the lowest colour liquor and putting down the outer surface of the crystal from the highest colour as it is the latter that is, in part, dissolved by the centrifugal wash water.

The use of syrup separators or molasses classification valves on centrifugals in refinery applications is not common, but they are used in a few cases. The mass balance above shows a modest differential in quality between the recycled and discarded runoff. Although the difference is small it is worthwhile as it allows more material to be recycled on account of its lower colour. It also provides a simple way to define the recycle proportion and maintain a continuous blowdown rather than recycling all of the runoff until the colour becomes unacceptable then rejecting a whole batch.

Excess washing of sugar in the centrifugal reduces yield and leads to increased purity runoff. If the plough mechanism leaves excess sugar on the screens to be washed off then this also increase runoff purity. Both of these occurrences give a greater opportunity for a syrup separator to capture more of the higher purity / lower colour material for recycling. The worse the yield the more valuable the separator becomes.

6. Equipment Size

Towards the end of the 20th century the unit sizes of equipment manufactured for the sugar industry increased and centrifugals of 1750 to 2100 kg massecuite capacity became the standard offering. Batch vacuum pans of 60 to 100 m³ are also widely used and continuous pans such as the VKT will produce over 60 t/h of sugar from a single unit. This trend to larger unit sizes is driven by the economics of manufacture and by the lower installed and maintenance costs of a smaller number of larger units.

For a modest sized refinery of around 1000 t/day the modern equipment can seem rather large. To produce 45 to 50 t/h of white sugar requires only two 60 m³ vacuum pans, one strike receiver, three centrifugals and a single white sugar conveying and drier/cooler system

The availability of these larger equipment sizes does make the traditional 4 boiling scheme look rather cumbersome, as it would tend to require a larger number of smaller plant items in order to be effective and provide adequate flexibility at each stage.

The single strike white boiling schemes on the other hand are a good fit to the modern equipment, providing the economy of scale with a large output of a single quality sugar. In our opinion any refinery design of up to 2000 t/day of sugar output should seriously evaluate the single strike option to compare the total installed cost against the traditional 4 strike approach.

7. Location of decolourisation processes

Traditional refinery practice is to use secondary decolourisation process, for example granular activated carbon or ion exchange resin, to treat the liquor prior to it entering the boiling scheme. The emphasis has tended to be on driving down the colour to lower and lower levels in order to allow better yield for a given sugar quality, to allow 4th strike sugar to be sold or just to reduce the total product colour.

Such an approach is also beneficial to recycling boiling schemes, as it allows more recycling within the constraint of a certain sugar colour.

Decolourisation is a separation process in the same way that crystallisation and centrifuging are. Such processes can be used in different sequences to achieve the same effect. There is no law that says decolourisation must come first. For the colour remaining in the liquor after primary processing (carbonatation) then there is some logic in removing the colour at the earliest opportunity. “Colour makes colour” is a phrase heard from time to time, so getting it out of the system early is a good idea.

For colour formed in the vacuum pans and liquor storage tanks the presence of a fine liquor decolourisation process is not helpful. This colour is not removed and hence it tends to accumulate in the system and increase colours. Some refineries with char houses take the opportunity to pass jet syrups through char cisterns to reduce their colour, and the Russian boiling scheme recycles runoff back to the carbonatation system where there is an opportunity for further colour removal. In both these cases there is a mechanism for removing the colour that is formed during processing.

So does it make sense to decolourise only before the pan house? To test this theory out a decolourisation unit was added to the Sugars model of the boiling scheme. The results of the calculations for a constant feed rate are shown below in Table 6.

Location	Feed	Feed	Recycle
Decolourisation	50%	80%	50%
Runoff discard %	27	11.5	5
Runoff discard t/h	11.5	5.3	2.4
Solids recovery %	84.1	92.7	96.7
Runoff purity	96.5	93.0	87.6
Runoff colour	2056	2050	2015
Colour in ICUMSA	600	600	1770
Colour out ICUMSA	300	120	890
Flow into decolourisation	56	56	34 m^3/h

Table 6. Comparison of Decolourisation Options

This initial modelling work suggests that decolourisation within the recycle loop of a single strike white sugar boiling scheme is more beneficial than additional decolourisation in the fine liquor feed.

There is a logical explanation to this finding. Firstly the colour generated within the process can be removed by the recycle decolourisation but not by the fine liquor option.

Secondly, the 50% decolourisation of the recycle reduces its effect on pan feed liquor colour, allowing more to be recycled for the same sugar colour. If the colour is doubled from feed liquor to runoff by the removal of 50% or more of the solids in the pan and centrifuge, then reducing the colour of the runoff by 50% returns it to its original colour level. In which case recycling more of it does not change the colour entering the vacuum pans.

There may come a point where ash, purity or some other consideration limits the amount that can be recycled, but a decolourised recycle would not present a colour problem.

The capital cost of a decolourisation system for the recycle loop would be lower than that for the feed liquor. The 40% reduction in volume flow will allow smaller diameter columns, pipes, valves and smaller pumps. Aiming for 50% colour reduction rather than 80% will reduce the necessary residence time and hence the total volume of columns and adsorbent (GAC or resin). A single pass system will easily achieve 50% decolourisation whereas for 80% a 2 pass system is more likely.

There appear to be significant capital cost advantages in decolourising recycle rather than fine liquor.

A similar logic could be applied to 4 strike series boilings – if the colour of the 4th strike sugar is problematic then one should consider decolourising the 3rd runoff / 3rd jet rather than pushing for even more decolourisation of the fine liquor.

These findings result purely from computer simulations with some simple assumptions about yield and colour transfer. They illustrate the concept that there may be more benefit in applying decolourisation in one part of the process than in another. This has been practised in char houses in the past and has been suggested for beet sugar processes also – decolourising of the 3rd product sugar before recycling to the white sugar boiling.

There is an opportunity for research work to look at the relative contribution of colour generated in the boiling scheme to the colour of the sugar. If this is significant then there may be merit in decolourising after at least one boiling stage.

If on the other hand the "manufactured" colour does not pass into the crystal in subsequent boilings then the benefit would be smaller. However, should this be the case, then in practice the colour elimination factor will be greater and the necessity for additional decolourisation would be reduced.

Figure 6 illustrates the use of decolourisation within a recycle loop :

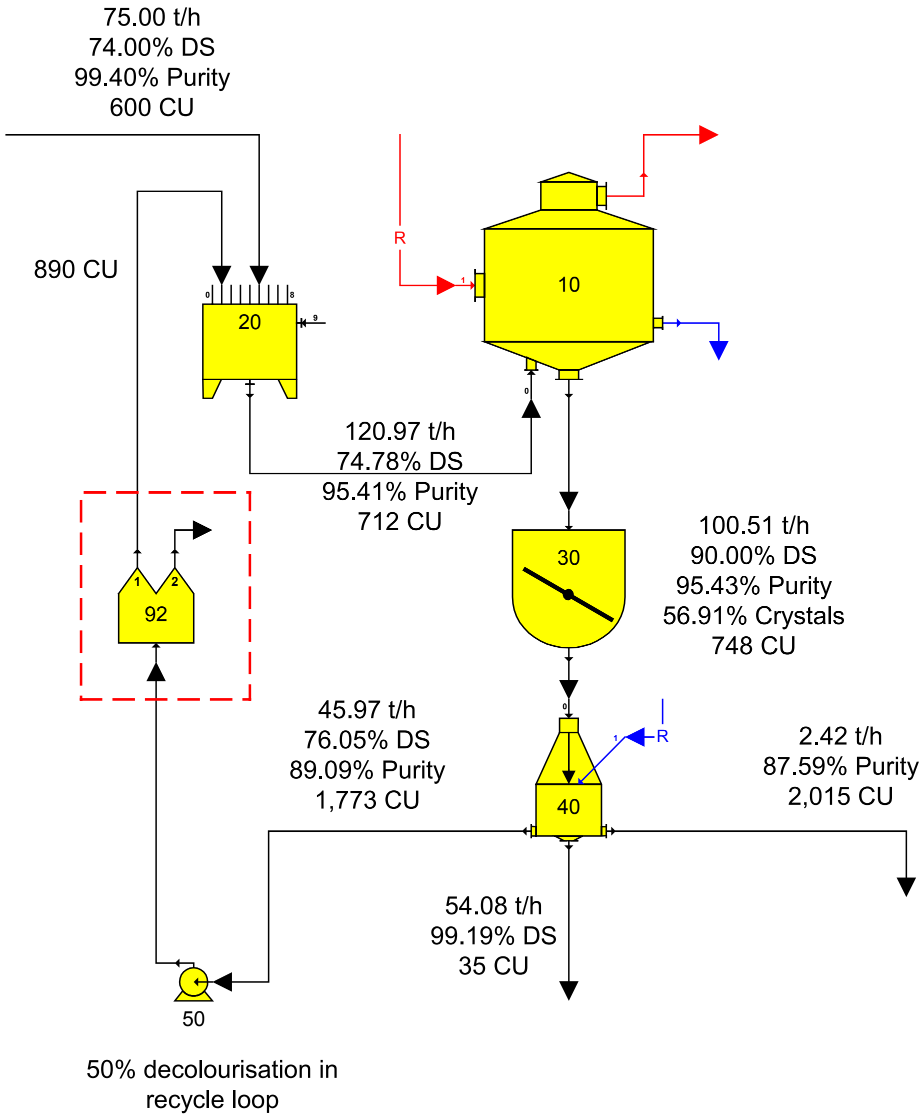

Figure 6 – Recycling single strike scheme with embedded decolourisation.

There are some practical considerations to address, for example the runoff syrup in the recycle loop will be at a higher brix than fine liquor and hence at a higher viscosity. The greater concentration of non-sugar material will also influence viscosity so the adsorption process may need to be designed for a lower operating velocity to reduce pressure drop. It may be that controlled dilution to a lower brix, perhaps around 70, is necessary for optimum decolourisation.

It is also necessary to understand the relative contribution of colourant in the fine liquor to the crystal colour, compared to the colour generated within the boiling process. If the generated colour compounds have a higher affinity for the crystal then this alternative location of decolourisation will be particularly effective.

If on the other hand the colourant from the fine liquor is the major component of colour in the crystal sugar then the traditional location may be better. In either case the decolourisation will remove both sources of colour from a stream in which they have been pre-concentrated by crystallisation of 50% of the dry matter. The pre-concentration is advantageous for the adsorption process which is not then required to achieve such low levels of outlet colour or such high percentage decolourisation.

8. Conclusions

The traditional model of a 10:1 colour elimination from massecuite to sugar is not supported by published refinery results and laboratory tests. An elimination factor of at least 15:1 rising in proportion to massecuite colour appears to be more representative of current practice in carbonatation refineries.

Refined sugar massecuite should give a dry solids yield of well over 50%, possibly as high as 60%. To achieve 50% requires a low crystal content in the vacuum pan or a very low crystal recovery in the centrifugal. When calculating boiling schemes dry solids yields of 55 or higher are probably justified.

White sugar can be produced by single strike boiling schemes to the same quality as in the traditional series of strikes with sugar blending. The yield is determined by colour considerations. With low feed colour and high colour elimination factor the yields of a single strike with runoff recycle will be equivalent to approximately 3 boilings in series.

A single strike system may require an additional boiling making sugar for remelt in order to reduce the solids loading on the recovery station.

The large size of modern equipment makes single strike boiling schemes attractive as a small number of plant items is required with no blending of solids and reduced complexity.

Incorporating a decolourisation process into the recycle loop of a single strike boiling system is potentially more effective than seeking to achieve higher levels of decolourisation in fine liquor. The reduced volume flow, higher colour inlet and outlet levels and reduced percentage decolourisation all work in favour of a smaller cheaper system. A similar argument applies to decolourising runoff / jet syrup from the 2nd or 3rd boiling of a 4 strike system in order to reduce product colour and/or allow the blending of 4th or 5th strike sugar into a single white sugar product.

Some further work is required to assess the relative contribution to refined white sugar colour from fine liquor and colour generated within the boiling scheme. The larger the contribution from the latter the more the benefit of decolourisation at a later stage in the process than current practice.

References.

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