Design Factors Which Affect the Heat Balance of a Beet Sugar Factory

E. B. COLE[1]

For the past several years this writer has watched with considerable interest two specific items of operating data; namely, percent steam on granulated sugar, and percent fuel on granulated sugar. As we have increased our production and have modernized our plants these data have shown a steady and very gratifying improvement. I have often speculated as to just how far we can go in improving our factory heat balances, and have been on the alert for improvements in design which will enable us to achieve the practical maximum efficiency in the factory heat balance.

Curiosity has compelled me to make comparisons between the performance of our plants and those of our neighbors. Each year's final performance figures show a definite pattern in the arrangement of factories according to their thermal performance. There is a limited amount of shifting up and own scale, but the same factories usually fall within the same groups from year to year.

I have chosen a fuel unit of 1 million btu's which is equal to 100 pounds of standard 10,000 btu's per pound coal or 1,000 cubic feet of standard 1,000 btu's per cubic foot gas, and will compare this with a standard 100-pound equivalent bag of sugar on a percentage basis.

Of the 52 factories whose records were studied, I find that "Fuel percent on granulated sugar" ranged from 59.5 percent to 144.3 percent with the mean value at 88.2 percent. The first ten factories produced granulated sugar for 70 percent fuel on sugar or less. The last ten factories produced granulated sugar for 100 percent fuel on sugar or more. It is interesting to speculate on the amount of money which could be saved by the sugar industry as a whole if all the stragglers could be moved ahead into the less than 70 percent fuel on sugar group.

I have found that the data "Steam percent on sugar produced" are accurate measures of the thermal and process efficiency of the sugar factory and these data permit of an accurate comparison between Steffen and non-Steffen sugar factories.

It is this writer's opinion that there is still room for much improvement in reducing the amount of steam and fuel required to make granulated sugar.

To provide a basis for the remainder of this discussion a heat balance which might be typical of a most efficient beet sugar factory is presented in Table 1. This table does not attempt to present a detailed heat balance, but merely a form of summary sheet. This heat balance is in very close agreement with actual operating conditions at our Rupert and Nampa sugar factories, and represents a non-Steffen House factory.

[1] Assistant Chief Engineer, the Amalgamated Sugar Company, Ogden, Utah.

In addition to assuming Table 1 for steam requirements we will also assume that there is an amount of water to be removed by the evaporators equal to 105 percent on beets.

What is the minimum total steam requirement and how can that minimum be achieved? In this case, if the vapor circuits were so arranged that the 105 percent water on beets was completely evaporated in supplying vapors for the various heating requirements, then the irreducible minimum would be 58 percent steam on beets or 425 percent steam on sugar produced. At the other extreme, if live steam or exhaust were used for all heating requirements and the 105 percent water on beets was vaporated in a five-body multiple effect evaporator without vapor extraction, the total steam required would then be 79 percent steam on beets or 579 percent steam on sugar.

In neither of the above examples was there any waste of steam nor was there assumed any decrease in process efficiency. Thus, for this sugar factory there is a difference of about 21 percent steam on beets in the total steam consumption figure between full utilization of vapor for heating and no utilization of vapors for heating. This is a variation of more than a third in the total steam requirements.

The arrangement of the vapor circuit which will permit the most effective use of vapors for heating and which at the same time is extremely practical to operate and maintain is one of the most important design factors which affects the heat balance of the sugar factory. Table 1 also indicates a vapor circuit which utilizes vapors to a maximum and which at the same time is practical and thoroughly workable with present day equipment and raethods. The flow sheet following the table indicates the approximate temperatures and pressures to be employed and also shows the location of the vapor recompressor in the circuit. The latter is the only novel feature of this particular vapor circuit. Time and space do not permit a detailed comparison of this vapor circuit with other circuits of modern design.

I should like to point out the effect that a change in diffuser draft has on the steam consumption of this typical factory and also estimate the effort that increasing the circulating load in the sugar end has on the heat balance. An increase in the draft of 10 percent on beets will raise the steam consumption to 67.90 percent on beets, an increase of 3.3 percent steam on beets. A decrease in draft of 10 percent on beets will lower the steam consumption to 61.84 percent on beets, a decrease of 2.76 percent steam on beets. An increase in the circulating load in the sugar end which would increase the stock in process by one-third would increase the steam consumption to 70.20 percent on beets, an increase of 5.60 percent steam on beets.

At this point I would like to discuss the much maligned thermal vapor compressor. It is nothing more or less than a steam injector with the suction line connected to the vapor line from one of the evaporator bodies; it discharges into the low pressure steam or exhaust line, and uses non-superheated live steam at boiler pressure as motive steam. The efficiency of this device is low, of the order of 25 percent at the very best, but compared to a mechanical vapor compressor its cost is very low and it is simple to operate.

Assuming that the power plant will supply 40 percent steam on beets *in* the form of exhaust to the evaporators and melters, then 14.60 percent steam on beets as makeup must come from some other source.

If third vapor is compressed from a five-effect exaporator, it will require 11.68 percent live steam on beets to recompress 4.87 percent third vapor to give a new total steam figure of 61.68 percent steam on beets.

For this particular plant, it is believed that a static thermal vapor compressor installation could pay for itself on a production of half a million bags of sugar. Don't be misled, unless the installation is favorable and is designed for optimum conditions, the returns might not justify the cost of the installation.

The quantities of steam and fuel required to make a bag of sugar are very nearly the same for either the Steffen House factory or a non-Steffen House factory. Any differences are due principally to the greater circulating load in the sugar end due to the higher burden of non-sugars in the sugar end of the Steffen House factory.

The power required to produce a bag of sugar is also very nearly the same for both Steffen House and non-Steffen House plants. This assumes that the plant is of a well balanced mechanical design with pumps and motors operating at near full load and that there is a minimum of pipe line friction, and line shafting with journal bearings and fiat belt drives. This typical factory with an efficient process and steam circuit must have an efficient mechanical plant if it is to take full advantage of the economies of low pressure steam and power generation.

The boiler plant in a sugar factory is essentially a process steam producer and as such it should be designed to produce process steam at the lowest possible cost and make only as much power as an efficient mechanical plant will require.

What are the power requirements for a mechanically efficient sugar factory? A non-Steffen House factory should require not more than 20 kwh per ton of beets per hour or 7.33 kwh per bag of sugar per hour. A Steffen House which works a reasonable amount of molasses, say 4.0 percent on beets, will then add 3 kwh per ton of beets per hour or 0.05 kwh per bag of sugar per hour. A pulp drier will add 3 kwh per ton of beets per hour or 1.1 kwh per bag of sugar per hour. A C. S. F. plant will add 2.0 kwh per ton of beets per hour or 0.75 kwh per bag of sugar per hour, and will consume exhaust at a rate which will produce at least twice as much power as is required by the C. S. F. plant.

Let's assume for the sake of easy figuring that this typical efficient sugar factory is a 2,400-ton per day factory with a pulp drier. It will then require 2,300 kwh, so we shall install a 2,500-kw generator which will operate at a load factor of 92 percent.

With all pans on it will require 54.60 percent exhaust on beets to process. With the white and intermediate pans off there is 40.20 percent exhaust required for process; this latter is the most unfavorable condition for the power plant. Therefore, we shall select steam conditions which will produce the required 2,300 kwh for 40 percent steam on beets to the turbine. Forty percent steam on beets in this case is equal to 80,000 pounds of steam per hour. Thus, it is necessary to generate 2,300 kwh with 80,000 pounds of steam per hour or one kwh for 34.8 pounds of steam per hour.

A look at the flow sheet reveals that the maximum back pressure is 35 psia or about $21^1/_2$ pounds gage saturated at the elevation of our Nyssa factory. Resorting to a Mollier steam diagram and a table of steam rate factors, we find that throttle conditions at the turbine need be only 177 pounds gage and 492° F. total steam temperature, or a superheat of 115° F.

This same plant with the addition of a Steffen House and C. S. F. plant would require 2,800 kwh, and would have a 3,000-kw generator which would consume a minimum of exhaust steam to process of 109,000 pounds per hour. The steam rate for the turbine would be 38.9 pounds of steam per hour per kwh. Throttle conditions in this case would be 147 pounds gage at 468° F. total temperature of 102° F. superheat.

Let's compare this plant with another one which has an identical process and low pressure vapor circuit, but instead operates with an exhaust pressure of 50 psi absolute or $36^1/_2$ pounds gage, saturated steam conditions. To generate 2,300 kwh with 80,000 pounds of steam per hour or at a steam rate of 34.8 pounds of steam per hour per kwh will require throttle conditions of 256 pounds gage at 520° F. total temperature or a superheat of 114° F. This same piant, but with Steffen House and C.S.F. plant, would require throttle condition of 217 pounds gage and 495° F. total temperature or 100° F. superheat.

Which of these two boiler and power plants is the more efficient?

The low pressure plant is very slightly the more efficient plant. Reference to a steam turbine handbook will bear out the point that the overall engine efficiency of a standard steam turbine generator set below the size of 7,500 kw is usually a few points better for the lower pressure machines. In this case, the 180 psig machine had an overall engine efficiency of 69 percent while the 260 psig machines had an overall engine efficiency of 68 percent. The actual steam rate in both cases was the same, as was the load factor.

A comparison of boiler efficiencies under conditions of identical design, and identical and optimum combustion practices, shows that the lower pressure boiler will have a flue gas temperature 30° F. lower than the higher pressure boiler and an overall efficiency of 0.9 percent point higher than the higher pressure boiler.

These two boiler and power plants are very nearly of the same efficiency with a slight advantage in favor of the lower pressure plant. Both sets of steam, exhaust, and power conditions represent good design.

Now let's compare both of these plants with one which operates at a steam pressure of 450 pounds gage pressure and a total steam temperature of 575° F. and produces exhaust at $36^1/_2$ pounds gage pressure. Referring to the Mollier chart and the steam turbine hand book we find that the actual steam rate is 27.2 pounds per hour per kwh; the load is 2,300 kwh at a load factor of 92 percent; the overall engine efficiency is 66.6 percent and the quantity of exhaust steam produced is 62,600 pounds per hour of exhaust at $36^1/_2$ pounds gage and 1.3 percent moisture, or 31.3 percent exhaust on beets.

How will the boiler efficiency of this last power plant compare with the first two? Under identical conditions of design and operation the last boiler plant will have a flue gas temperature which is 81° F. higher than the boiler plant which operates at 177 pounds gage and will suffer an additional loss of 2.1 percent in boiler efficiency compared with the 177-pound boiler plant.

Up to this point I have avoided mentioning the costs of building these three boiler, power plant, and evaporator stations. It should be obvious that the lower pressure plants are the least expensive to build. The low pressure plants can use standard weight pipe and 300-pound class fittings. The other plant requires extra heavy pipe and higher pressure fittings. *In* the standard class of turbine generators the first major price break is at 500° F. temperature and 250-pound design pressure. Furthermore, in order for the 450-pound boiler to compete with the 177-pound boiler in operating efficiency it will be necessary to add to the boiler an economizer, or an air heater, at an added cost.

Percent Sugar in Beets	16.10%
Total of Known and Unknown Losses	0.45%
Sugar in Molasses Produced	2.00%
Sugar Produced	13.65%
Extraction	84.8 %

Steam Requirements	Total	Stm.	IV	2V
Diff. and R. J Htr.	11.50		3.50	3.50
J. Blr. or 2nd Carb.	3.50			3.50
Tn. J. Htr.	6.25		4.00	2.25
Tk. J. Htr.	1.10			1.10
White Pan	12.00		2.00	
Int. Pan	6.00		6.00	
Raw Pan	3.65			3.65
Melters	1.50			1.50
Granulators	1.50			
Misc. Heating	1.00			1.00
Beet Slicers	1.50	1.50		
Rad. and Unknown	8.50	3.50		
	58.00	5.00		
I x 25.50 =	2 50			105
2 x 16.50	33.00			— 72 5
3 x 4.50 =	13.50			)33
				6.60
				46.50

% Ehaust to Evaps. %	53.10
Exhaust to Melters	1.50
% Exhaust to Process	54.
% Steam to Slicers	60
% Steam and Exhaust Losses	1.50
	8.50
% Steam on Beets %	
Steam on Sugar %	64.60
Fuel on Sugar	473
	55.7

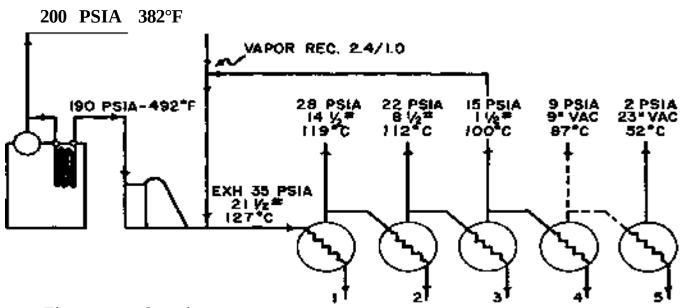

Figure **1.—Flow** sheet.

Thus, in order to produce sufficient power and produce process steam for a beet sugar factory at the lowest possible first cost and operating cost, I would choose the boiler plant and turbine which operate at no more than 200 psia and 500° F. total temperature.

I would like to point out that, in order for a plant to be capable of the most efficient heat balance, it must have an efficient and capably managed process, it must be sparing in its use of steam at each heater or process station, the arrangement of the vapor circuit must take full advantage of the economies of multiple effect evaporation, and lastly—the boiler and power plant must be designed to produce steam and power at the lowest possible cost.

The steady trend toward more complete mechanization within the sugar factory is in step with the times. However, care should be taken to see that the mechanical devices which are installed are efficient in their use of power, and that their use of power is justified. Mismatched motors and pumps can waste power, oversize motors can waste power and lower the power factor, awkward piping arrangements and undersized pipe lines can waste power. In fact, it demands continuous vigilance to be sure that, as equipment is added or changed, the power system is not overloaded.

In conclusion, I would like to state that it is possible to build and operate efficiently a sugar factory which will produce sugar for 60 percent fuel on sugar or less, and this sugar factory need not operate its boiler at more than 200 pounds pressure. In fact, the low first cost low pressure plant will als;o produce steam, power and sugar at the lowest possible operating cost.

I hope that the presentation of this paper will promote a discussion which will continue long after this meeting has been adjourned.