A PERFORMANCE COMPARISON OF HEAT EXCHANGERS USED IN PHOSPHORIC ACID EVAPORATION

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Introduction

A number of different heat exchanger designs for use in low-pressure phosphoric acid evaporation have been operating at the Suwannee River Chemical Complex (SRCC) of Occidental Chemical Company in recent years. Three different heat exchangers consisting of a "large" hole impervious graphite unit, a shell and tube impervious graphite unit, and a shell and tube metal unit will be compared in approximately 40% wt P_2O_5 service. Two other heat exchangers consisting of a shell and tube impervious graphite and a "small" hole impervious graphite block unit in approximately 50% wt P_2O_5 product service are also represented. In total five (5) heat exchangers will be examined in this presentation.

The mechanical design aspects of the units will be compared and discussed along with comments about the recent installation of some of the units. A performance comparison of the units based on actual production plant data will be presented.

Mechanical Description

The heat exchangers are designated as unit "A" through unit "E" in this paper. Units "A", "B", "C" are in 40% P_2O_5 service and units "D", "E" are in 50% P_2O_5 service.

The first exchanger (Unit "A") is a large diameter process hole (1 3/8 inch, ID) impervious graphite block heat exchanger which was retrofitted to an existing evaporator in November, 1982. This block exchanger replaced an existing shell and tube impervious graphite unit which was part of the original evaporator design. The unit was sized by the vendor to match the inside process area of the original tube and shell graphite unit it replaced.

The second exchanger (Unit "B") is a shell and tube impervious graphite heat exchanger which is mechanically similar to the original heat exchanger replaced by unit "A", above. This shell and tube heat exchanger has the same mechanical details as the original design except for a steam distribution "jacket" which was added a number of years ago to reduce steam side tube vibration. This allows higher than designed steam rates to be used on the exchanger.

The metal shell and tube heat exchanger (unit "C") is an experimental unit designed by Occidental Chemical Company using Hastelloy-G tubes (1½ inch OD, 0.120 inch wall thickness). This exchanger replaced a shell and tube graphite heat exchanger in similar service to the above mentioned units. This unit was placed into service in early 1983.

The next exchanger (Unit "D") is mechanically the same as previously mentioned "B" unit which is a shell and tube impervious graphite exchanger.

The last exchanger (Unit "E") is a small process hole (5/8 inch, ID) impervious graphite block heat exchanger which was installed in mid-1982.

The mechanical details are summarized on the next page in Table 1.

Table 1

HEAT EXCHANGER MECHANICAL DESIGN SUMMARY

Unit Designation	A	B	C	D	E
TYPE	BLK	S & T	S & T	S & T	BLK
Material Of Construction	Impervious Graphite	Impervious Graphite	Hastelloy G	Impervious Graphite	Impervious Graphite
No. Process Holes (BLK)[1] No. Tubes, (S & T)[2]	355	— 362	425	362	868
Process Hole ID, in (BLK) Tube ID, in (S & T)	1 3/8	1½	1¼	1½	5/8
Process Hole Length, ft (BLK) Tube Length, ft (S & T)	26	23	19.9	23	18.8
Process Side, Acid Surface Area $(ft)^2$	3270	3270	2789	3270	2685
Service Steam Surface Area $(ft)^2$	3155	4359	3266	4359	2656
Shell Diam, in OD	52	52	44	52	50
Overall Length, ft	26.75	25.3	19.9	25.3	23.25
Steam Distribution	3 Inlets	Dist.Belt	Dist.Belt	Dist.Belt	3 Inlets

Notes:
1. BLK: Block Unit Construction
2. S & T: Shell and Tube Construction

Installation And Maintenance

The installation of the impervious graphite block heat exchangers in new installation, unit "E", and in a retrofitted situation unit "A" presented no particular problem.

The small hole block unit was assembled directly on the evaporator then pressure tested, successfully.

The retrofitted block exchanger was assembled on the ground near the evaporator then lifted into place. The unit was then pressure tested. It also passed the pressure test successfully. Some modification of the steam and condensate piping was necessary to complete the installation on the service side of the unit. The circulation piping was also modified to allow for a slightly longer heat exchanger than the original shell and tube unit.

Successful installation of block units, based on these cases, appears not to be dependent upon the assembly location at the final plant site. Rather, the careful assembly of blocks, gaskets, and shell is necessary for a successful installation.

No maintenance problems have been experienced on either block heat exchangers to date. No visual errosion of the heat exchanger inlet of unit "E" due to high tube velocity has been noted and none is expected. The unit has been in service only a short time and it is checked periodically for evidence of this.

Comparison Of Results

The evaporator heat exchanger performances are summarized in Table 2, below. The means are based on operating data on each unit over an approximate 50 day period between 1983 and early 1984. This information is plant data which is subject to the usual problems associated with operating data.

The information about the feed and product characteristics is self-explanatory. The steam flow is pressure corrected. The LMTD is the logrithmic mean over-all temperature difference. The area refers to the inside surface area of the heat exchanger on the process side of the unit. This area has been reduced in some cases, compared to that reported in Table 1, due to plugged tubes in the shell and tube exchangers.

The U (inside) term is the over-all heat transfer coefficient calculated using the following equation:

$$U = \frac{M * \lambda}{A * LMTD}$$

Where:

U	=	Ht transfer coeff., BTU/Hr(ft)^2 Deg. F
M	=	Steam flow to heat exchanger in Lbs/Hr
λ	=	Latent heat of vaporization of saturated steam at the chest pressure of the heat exchanger, BTU/Lb
A	=	Inside area of heat exchanger, ft^2
LMTD	=	Logrithmic mean overall temperature difference, Deg. F

TABLE 2
EVAPORATOR HEAT EXCHANGER PERFORMANCE DATA

	LARGE HOLE BLK	S & T GRAPHITE	S & T METAL	S & T GRAPHITE	SMALL HOLE BLK
	UNIT A	UNIT B	UNIT C	UNIT D	UNIT E
	MEAN	MEAN	MEAN	MEAN	MEAN
PROD, WT% P2O5 (TOTAL)	41.78	40.23	35.74	51.42	50.36
PROD, SPECIFIC GRAVITY	1.537	1.531	1.409	1.681	1.679
PROD, WT% SOLIDS	3.79	5.20	3.60	3.87	4.03
FEED, WT% P2O5 (TOTAL)	29.75	30.54	26.72	42.33	43.24
FEED, SPECIFIC GRAVITY	1.344	1.366	1.307	1.529	1.552
FEED, WT% SOLIDS	1.87	3.28	1.92	2.96	3.76
STEAM FLOW, LBS/HR	55926.	56795.	40228.	25278.	24619.
CHEST PRESS, PSIA	20.52	17.96	18.09	22.76	20.80
HT EXCH. INLET TEMP., F	174.81	178.82	161.33	175.60	160.25
HT EXCH. OUTLET TEMP., F	184.98	187.30	169.52	179.64	165.78
LMTD, DEG F	49.22	38.92	56.61	57.35	66.76
AREA (INSIDE), (FT)2	3270.	2954.	2743.	2944.	2685.
U (INSIDE), BTU/HR(FT)2 F	336.5	492.4	247.0	146.5	131.1
CIRCULATION RATE, GPM	12488.	15850.	11852.	16146.	9475.
TUBE VELOCITY, FT/SEC	7.57	8.80	7.30	8.99	11.41

The tube velocity was calculated based on an enthalpy balance across the heat exchanger.

An attempt was made to try to correlate these U's to standard parameter such as tube velocity V, hole diameter D, and density ρ used in heat transfer calculations. The results were inconclusive, which is not surprising given the amount of data present and the conditions under which it was taken.

However, the point must be made that all of these heat exchangers are working satisfactorily. No evaporator production restriction has been experienced due to poor heat exchangers performance to date.

While the overall U is an important point in evaluating a particular heat exchanger, the economics of a particular unit must be based on each site location requirements.

The block heat exchangers have a higher capital cost than shell and tube graphite units. However, this is offset by maintenance cost savings and condensate recovery in a block exchanger compared to a shell and tube graphite unit.

The overall economics of the various exchangers can be summarized on a relative basis to impervious graphite shell and tube unit as follows:

Table 3
Economics

	Graphite Shell & Tube	Graphite Block	Metal Shell And Tube
Relative Capital Cost	1.00	1.5	2.0
Annual Maintenance Costs As Fraction Of Capital Cost	0.10	0	0.05
Incidents Of Condensate Recovery Failures Per Year	4	0	2

Conclusions

The choice depends upon the value of condensate recovered and the maintenance cost savings achieved by the impervious graphite block or metal exchanger versus the incremental capital requirements of these units, compared to the conventional graphite shell and tube exchanger.

Occidental has experience with all and finds that replacement of existing shell and tube units with carbon block units can be justified under certain circumstances. Occidental intends to continue to explore the economic feasibility of replacing shell and tube units with the block type design.