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Packless Cold Trap Evaluation

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TECHNICAL DATA RECORD		PAGE 1 OF 12			
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		STATEMENT OF PROBLEM <p>To evaluate the performance of the four cold traps of advanced packless design and recommend a test program for the LCTL packless trap.</p>			
		ABSTRACT <p>Presented is a discussion of precipitation and crystallization theory as applies to the sodium-sodium oxide system. HNPF packed and packless trap performance is compared. Cold trap analytical methods are presented. Recommended are a test program for the packless trap installed in the LCTL, and improvements of design for future traps.</p>			

INTRODUCTION

The rendering insoluble of a substance in solution is termed crystallization at high concentrations of solute and precipitation at low concentrations. The process is accomplished by chemical reaction or change in temperature (usually lowering) of the mixture. The latter mechanism is used in a cold trap to remove sodium oxide and is appropriately called precipitation because of the very low solubility of sodium oxide ($< 1\%$) over a wide range of temperatures (up to 1000°F).

Crystallization or precipitation occurs in two steps (a) crystal or particle formation called nucleation and (b) crystal growth. In different ways, both depend on the degree of supersaturation and are illustrated in Figures 1 and 2. The first graph of temperature vs concentration shows the normal solubility curve A and the Miers supersolubility curve B.

FIGURE I
Solubility and Supersolubility Curves¹

No nucleation or growth occurs in the undersaturated region. Nucleation can occur in the metastable region through any of the following mechanisms:

(a) Mechanical impact - vigorous stirring, wall collisions, collisions with nucleation baffles, and impurities.

(b) Catalytic effect - similar to mechanical impact involves solution collision with crystals or particles already present.

(c) Local concentration variation - solvent evaporation at surface, cooling near walls, splashing, etc.

Nucleation occurs in the labile region spontaneously. Crystal growth occurs as the nucleus moves through the metastable region to the solubility curve. If the metastable region is large, and the conditions listed above are not present, crystal growth can occur for some time without nucleation thus forming sizable crystals. The evidence from sodium fires and cold trapping experience seems to indicate that the metastable region for sodium oxide in sodium is rather narrow; consequently nucleation occurs quite readily and crystal growth is not extensive. This situation can be illustrated with Figure II, which represents rates of spontaneous nucleation and crystal growth as a function of supersaturation.

When the metastable region is narrow, rapid rise in nucleation occurs and is more predominant than crystal growth through the region. (This, again, is the situation which likely occurs in the sodium-sodium oxide system.) It can also be seen that in such a system, if the temperature drop is rapid in the direction of flow (i.e. a cold trap) and the flow space is small, considerable

precipitation and possible plugging could occur in this region. Such situations were observed in the economizer³ and annulus⁴ section of two types of traps.

PERFORMANCE EVALUATION

Of the four existing packless traps (LCTL, Shellside Loop, Sample Preparation Loop, HNPF) only the HNPF trap has extensive operating data. Of interest at Hallam has been the efficiency and capacity of the packless trap.

The efficiency of a cold trap has previously been defined as:

$$(1) \text{ eff.} = \frac{C_i - C_o}{C_i - C_o^*}^2$$

where C_i = inlet stream oxide concentration

C_o = outlet stream oxide concentration

C_o^* = saturation concentration corresponding to minimum cold trap temperature

Difficulty seems to arise in the use of C_o^* , particularly in the packless trap at Hallam. A comparison of the bottom sections of a packed and the Hallam packless trap will indicate the reason.

FIGURE III
Cold Trap Bottom Sections

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The sodium circulating through the bottom section of the packed trap is cooled by convection and conduction through the trap wall; the oxide is trapped in the mesh before the bottom of the trap. The sodium temperature measured near the bottom of the trap is fairly uniform and accurately represents Co^* . The accumulation of oxide in the bottom of the packless trap and the presence of collection baffles virtually eliminates convection in the lower region. Consequently, a considerable temperature drop exists between the lower region and the region of flow immediately above the baffles. In order that the flowing sodium reach a low trapping temperature (250°F), the coldest temperature in the baffle region must be maintained below the freezing point of pure sodium (possibly as low as 150°F). This excessively low temperature results in erroneous interpretations of efficiency and the frozen sodium reduces the volume available for receiving precipitated oxide to more fairly assess efficiency. It is suggested that the control temperature be located above instead of in the baffle region of the packless trap.

The inlet concentration C_i is the concentration in the main sodium system and can be obtained directly from the main system plugging temperature. Co cannot be measured directly at Hallam but must be calculated from a material balance. The entire quantity $C_i - Co$ is calculated as follows:

$$(2) \quad W \frac{dC_i}{dt} = R_A - R_R$$

where: W = total weight of sodium, lbs

R_A = rate of oxide addition to the sodium system, lb/hr

R_R = rate of oxide removal by the cold trap, lb/hr

$$(3) \quad R_R = Q(C_i - Co) \quad \text{where: } Q = \text{side-stream sodium flow rate lb/hr}$$

Then:

$$(4) \quad C_i - Co = \frac{1}{Q}(R_A - W \frac{dC_i}{dt})$$

dC_i/dt is the slope of concentration vs time in the main system. When the trap is not activated, $C_i - Co = 0$ and $W dC_i/dt$ is a measure of R_A , assuming that the R_A measured before or after a trapping run is unchanged during a run.

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However, data from Hallam⁵ indicates that the rate of addition or appearance of oxide varies from time to time. Use of fuel handling equipment or cutting into a system can cause an unusual change in the addition rate. This unreliability of Ra also adds to the error in calculating efficiency and determining the influence of the independent variables on oxide removal. Disregarding possible errors caused by variation in Ra, analysis of the HNPF packless trap indicates the following:

(1) The packless trap removed 88 lb of oxide as compared to an estimated maximum capacity of 100-150 lbs⁶ and a measured capacity of 200# for the HNPF prototype packed trap².

(2) The efficiency ranged from 21.6% to 103.0%⁵ as compared to nearly 100% for all cases on the HNPF packed prototype.²

(3) The trapping rate was only about 1/3 as great as the mesh type trap subsequently used.⁷

However, increasing the volume available for oxide collection and location of the control thermocouples as previously suggested improve all three items.

ANALYTICAL METHODS

Cold traps may be operated in 2 ways; (1) with $T_i - T_o^*$ corresponding to a fixed concentration difference $C_i - C_o^*$, or (2) with the temperature T_o^* corresponding to a fixed ultimate C_o^* . The former method is often used to avoid a large ΔT and possible component plugging when C_i is fairly large. Of interest is the variation of the system concentration (C_i) with time for the two methods:

$$\text{Let: } C_i - C_o^* = \Delta C^*$$

$$C_i - C_o = \Delta C$$

For case #1 (constant ΔC^*), with the efficiency assumed constant, ΔC is also a constant. If the oxide addition rate (R_a) is assumed constant then from the material balance:

$$(5) \quad C_i - C_{ii} = (R_a - Q \Delta C) \frac{t}{W}$$

where C_{ii} = system concentration at time $t = 0$

The concentration vs time curve would be:

Figure IV

Concentration vs time, ΔC constant

Under the same assumptions for efficiency and oxide addition rate, the material balance for case #2 yields:

$$(5) \quad \frac{Q (\text{eff.}) (C_i - C_o^*) - R_a}{Q (\text{eff.}) (C_{ii} - C_o^*) - R_a} = e^{-Qt/w}$$

and the concentration vs time curve would be:

FIGURE V

Concentration vs Time, C_o^* Constant

In the analysis of cold trap performance, there seems to be two independent variables of operation: (1) the flow Q through the trap; and (2) the ideal concentration difference ΔC^* which is directly related to the system plugging temperature and coldest temperature in the trap. The only real dependent variable seems to be ΔC . Any other variables considered seem to be combinations of these three. That is, efficiency is $\Delta C / \Delta C^*$ and trapping rate is $Q \Delta C$. A general equation expressing the relationship between the three variables is:

$$(7) \Delta C = k (\Delta C^*)^n Q^m$$

If by holding Q constant it is determined through a series of tests varying ΔC^* that $n = 1$, then efficiency could be considered in evaluating the effect of Q , and equation (7) could become:

$$(8) \text{eff.} = k Q^m$$

If this is not the case, then substitution into (7) would give:

$$(9) \text{eff.} = k (\Delta C^*)^{n-1} Q^m$$

If we call trapping rate G , then the general equation for trapping rate would be

$$(10) \quad G = k(\Delta C^*)^n Q^{m+1}$$

TESTING PROGRAM

It is suggested that at least two test runs be performed on the LCTL packless cold trap. One run will vary ΔC^* while holding the flow constant. The other will be with a fixed ΔC^* while varying the flow. The data generated will be used to determine k , m , and n in equation (7). It is recommended that control be such that the temperature of a point near the inlet to the trapping section be kept at the system plugging temperature T_i . This is to assure that nucleation begins at the same location for all tests. It is suggested that this be done on the thermocouple which is at the inlet to the annulus in the cold trap. If this causes plugging in the annulus, then this control may be moved to the T/C midway down the annulus.

In the constant flow case, as the system concentration C_i and the plugging temperature T_i are reduced, the cooling to the trap will have to be increased in order to maintain the control point @ T_i ; this will automatically increase ΔC^* .

In the constant ΔC^* case, the sodium flow will have to be increased after the air flow cooling is increased in order to maintain a constant ΔC^* .

CONCLUSIONS AND RECOMMENDATIONS

As previously suggested, the minimum trapping temperature should be taken just above the baffle region in order to eliminate erroneous interpretation of efficiency. Whenever a cold trap is to be tested or checked extensively, it is recommended that provision be made for determination of the trap outlet plugging temperature, so that estimates of the outlet oxide concentration need not be made.

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Economic incentives indicate the desire to design a trap with a larger volume available for oxide collection. Also, a packless trap is suited to a design in which only the oxide collection portion may be discarded after each run⁶; it is also probable that a packless trap which permits draining in-site and be immediately re-useable, can be developed.

FIGURE VI
PACKLESS COLD TRAPS

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