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VENTILATION IN ELECTROWINNING AND ELECTROREFINING

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VENTILATION IN ELECTROWINNING AND ELECTROREFINING

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The ventilation of electrowinning cellhouses and electrorefineries is a complex problem. A systematic approach is developed to define the important contaminant generation rates including heat, moisture, and acid mist. Fluid dynamic scale modelling is discussed as a powerful tool for solving a building's flow field and contaminant concentration field. The other associated problems, including wintertime fogging in the building and the high costs of make-up building heat, are examined. The possibilities for reclaim of low-grade waste heat are presented and the economic impact evaluated. The payback periods of such schemes are generally shown to be favorable in the current economic climate.

Introduction

Issues such as air pollution, the health and safety of personnel, and energy conservation have a significant influence on the design of ventilation systems for electrowinning and electrorefining tankhouse operations. To meet the new legislated standards and related union-contracted agreements, many existing ventilation schemes will require major modifications. New tools are needed to solve these ventilation problems in an expedient and cost-effective manner.

This paper outlines a rational approach to the design of ventilation systems. Included is a description of new analytical and modelling techniques which have been used successfully to solve tankhouse ventilation problems. Although the principles discussed in this paper have a much wider application, practical examples will be limited to the electrowinning of copper, nickel, and zinc, and the electrorefining of copper and nickel.

Tankhouse Ventilation Problem Areas

To develop tankhouse ventilation concepts, the designer must consider:

- workplace environment
- outside environment (air pollution, noise)
- energy conservation.

As these three factors are interrelated, the development of rational designs is difficult and complex.

To produce acceptable solutions, appropriate design objectives must first be established. Each of the above factors must be considered separately, and each must be viewed in light of technical and economic constraints for proposed alternative ventilation schemes. Experience indicates that these design objectives are project-specific.

While design objectives for the outside environment and energy conservation are usually straightforward, problems exist in the development of workplace design objectives. In today's climate, an industrial hygienist is an essential member of a project design team responsible for setting design objectives for contaminants such as acid mist, arsine, and stibine, and physical agents such as heat stress, and noise. Guidelines for permissible exposures exist - the Threshold Limit Values (TLV's) for Chemical Substances and Physical Agents, as published by the American Conference of Governmental Industrial Hygienists, and are used in the U.S.A. and in Canada - but questions which pertain to plant management philosophy and economics must be resolved. What constitutes, for instance, an acceptable safety factor for design purposes for TLV's? The 8-hour time-weighted average for sulphuric acid mist is 1 mg/m^3. If a tankhouse has an acid mist problem, should the design objective be 0.1 x TLV or 0.5 x TLV or 1.0 x TLV?

Another more difficult problem is the establishment of the necessary design parameters which will ensure that the new or modified tankhouse will meet the accepted design objective. The prediction of heat stress levels for tankhouse operations illustrates this point. Some of the designer's concerns in the application of heat stress design objectives are:

a) ambiguity surrounding the definition of heat stress, which refers to conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects.

b) use of indirect measurements of environmental factors related to heat stress, because of the impracticability of monitoring workers' deep body temperatures. This results in numerous different equations for calculating heat stress, which in turn yield different answers.

c) subjective assessment of each work regime, required to establish the workload categories for different tankhouse operators.

To define ventilation objectives, then, proper judgement is needed. A well-developed system will increase the productivity of the work force, and in many cases, reduce the cost of long term health-related litigation and claim payments.

Selection Of A Ventilation Scheme

The Constraints

Table I summarizes the constraints on the selection of a ventilation scheme for a tankhouse operation.

Table I. Ventilation Constraints

Constraint	Contaminant	Ventilation Objective
Heat stress	Heat release	Establish a WBGT* within TLV
Explosions	Hydrogen release	10% Lower Explosive Limit in building
Fog formation	Evaporation	Proper wintertime make-up heat supply - no fogging
Quality of breathing zones	Acid mist Arsine Stibine Toxic metal dusts and mists	Must comply with TLV guidelines. Toxic gases should not circulate in general ventilation systems.
Sound levels	Noise	Maintain an 8 hr. TLV
Economic	-	Minimize capital & operating costs for system
Layouts	-	Easy maintenance access to system components

*Wet Bulb Globe Temperature

Not all constraints exist in any one cell or tankhouse, but usually four or five of them apply in all tankhouses. So, while the cost of power and make up heat impose a strong restraint on system sizing, occupational health and safety legislation no longer allow for ill-conceived and undersized ventilation schemes.

The Information Base

The primary information that must be developed is proper quantification of the contaminant release rates. These govern all subsequent design calculations. The information required will vary with the electrochemical process, and full consideration must be given to these differences. Key aspects which affect ventilation design are summarized in Table II for the various processes considered.

Table II. Ventilation-Related Process Conditions of Electrochemical Processes

Process	Electrolyte Temp. °C	Electrolyte Heat Requirement	Major Contaminant to Work Space	Electrode Lifting Cycle
		ELECTROWINNING		
Zinc	40	Cooling	Acid mist	24-48 hrs.
Nickel	60-70	Cooling	Acid mist, heat	1 day + 8-12 days
Copper	55/35*	Cooling	Acid mist	1 day + 5-8 days
		ELECTROREFINING		
Copper	60-65	Heating	Heat	8-14 days
Nickel	50-60	Heating	Heat	12-14 days

*Starter Sheets/Deposition Tanks

The approach to control of the contaminants is closely related to the contaminant, as well as to the actual process. The contaminants are consequently discussed by type, and illustrated with reference to specific processes. The principles appropriately applied will define the ventilation requirements for any one of the 5 major process groups shown in Table II.

Heat Losses and Evaporation Rates

A standard heat balance procedure can be used to establish the latent and sensible heat losses. The surfaces for a particular process are generally at well-known or easily established temperatures.

The convective component of the heat transfer coefficient from tank surfaces, exposed anode and cathode surfaces, bus bars, etc., is generally expressed in the form (Ref. 1):

$$h_c = 1.0 + 0.25V \qquad (1)$$

for V less than 16 ft./sec.

where h_c = Convective Heat Transfer Coefficient BTU/hr.ft.^{2}°F
V = Air Velocity in Forced Convection (ft./sec.)

At the temperatures of concern, radiation is typically the smaller part of the combined heat transfer coefficient. Similarly, evaporation rates can be computed from (Ref. 2):

$$W = K(VP_1 - VP_2)V^{0.8} \qquad (2)$$

where W = Evaporation Rate (lb./hr. ft.^{2})
$VP_{1,2}$ = Vapour Pressure of Fluid at Temperature of Fluid and at Ambient Air Temperature (mm Hg).
V = Air Velocity (ft./sec.)
K = Constant from experiment

Based on these equations and on field data, the significant sources of heat to a copper refinery, formulated on unit production rates, are shown in Table III. Also shown is the measured evaporation rate. Both heat and evaporation losses will vary from summer to winter due to:

a) changing ventilation rates summer to winter, and
b) changing ventilation air temperature and a fixed process temperature.

Table III. Typical Tankhouse Heat Loads

Source	MMBTU/Ton of Copper
Direct heat requirement of tanks	0.7
Indirect electrical heat to tanks	1.6
Lighting, motive power, electrical losses	0.2
Total	2.5
Evaporation rate (tons water/ton Cu)	0.2 - 0.4

Acid Mist Generation

Electrowinning processes, such as zinc sulphate electrolysis, release hydrogen at the cathode, and oxygen at the anode. At 90% current efficiency, approximately 8000 SCF of oxygen and hydrogen or 0.25 tons of gas are released per ton of cathode. This gas release from the cell surface produces acid mist. Many additives have been tried to keep the mist under control. The concept of source capture under a stable foam layer is attractive, due to low cost and minimum operational interference. Licorice, cresyllic acid, bone glue, gum arabic, Dowfroth 250, and others have been used in various combinations with varying degrees of success. Generally, control of foam depth is a problem. Excessive foam generation elevates the trapped hydrogen to the cell electrical contacts, giving high risk of explosion or fire.

To evaluate the effectiveness of foam, the ventilation data from several enclosed tankhouses was reduced to a compatible basis. For the comparison, it was assumed that the mist generation rate per square foot of cell liquid surface is proportional to the gas flow rate through the liquid surface, or:

$$m = Kq/A_L \qquad (3)$$

where m = Mist generation/ft.^{2} of surface (lb/ft.^{2} hr.)
q = Gas volume rate/cell (ft.^{3}/hr.)
A_L = Liquid surface of the cell (ft.^{2})
K = Constant

This can be rearranged on the basis of the whole tankhouse to give a relationship of the form:

$$M = K_1 .N. A_C.C. [1.5 - E] \qquad (4)$$

where M = Total cellhouse mist release (mg/hr.)*
K_1 = Constant for a given foam and thickness
N = Number of cells
A_c = Area of cathodes per cell (ft.^{2})
C = Current density (amps/ft.^{2})
E = Chemical current efficiency after subtraction of stray currents and shorts.

From Figure 1, based on data from six tankhouses, K_1 and foam thickness are clearly related. The lowest mist levels are based on data from a 30 cell pilot plant using meta-para-cresol (M.P.C.) as a foam stabilizing agent (Ref. 5). This agent is effective, though not yet proven in full-scale practice. It is also known from test work in three tankhouses that addition of M.P.C. does not adversely affect the current efficiency.

Using this data, the applicable rate of mist generation can be predicted.

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* mg/hr. is used so a direct calculation of mg of mist evolved is possible. TLV's for acid mist are expressed in mg/m^3.

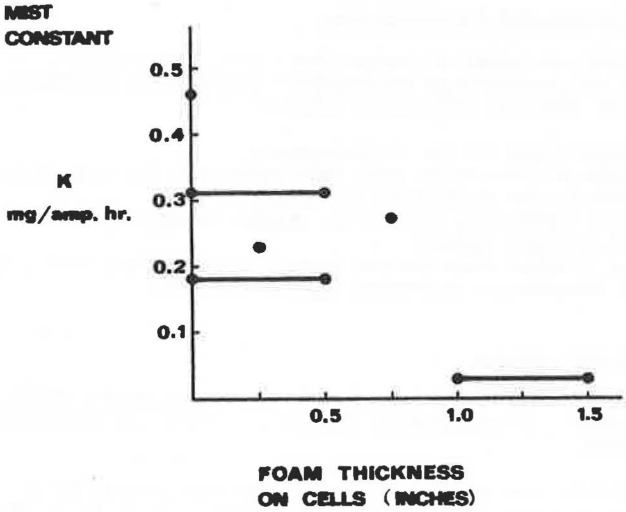


Fig.1 MIST GENERATION AS A FUNCTION OF FOAM THICKNESS

Hydrogen Release

Hydrogen release results from electrochemical inefficiency on processes operating at voltage potentials larger than the hydrogen potential. For zinc sulphate electrowinning, for example, an overall current efficiency of around 90% is typical. This level is very sensitive to impurity levels, electrolyte temperature, and current density. With an estimated 3% loss attributed to stray currents and shorts (Ref. 3), 7% of the impressed current can be assumed to generate hydrogen by electrolysis of water. As a design basis, however, the more important criterion should be the minimum likely operating current efficiency during chemical upsets, corresponding to maximum hydrogen generation (80% is a typical figure for this, with 17% of the current electrolysing water).

Based on 22,500 amps/cell, the hydrogen generation rate would then be 2.2 SCFM/cell. For a tankhouse with 800 active cells, this gives 1760 SCFM of hydrogen. The Lower Explosive Limit of hydrogen in air is 4.1% (Ref. 4), so to keep to less than 10% of the Lower Explosive Limit requires a minimum of 430,000 SCFM of exhaust air. The 10% factor is taken to minimize risks of high concentration pockets building up, and the attendant fire hazard.

Other Information Required for Design Base

Several other categories of design data - i.e., the routine ventilation and air conditioning information - are required to develop the most economically effective ventilation schemes:

- local degree days for the heating season
- local cost of alternative fuels when normalized for heat transfer efficiency to the ventilation air stream
- local wind conditions, directions, average strength
- wall construction details
- required internal temperatures, from occupational health criteria, comfort criteria, or to protect against freezing.

Fog and Surface Condensation

Based on data developed for evaporation rates, ventilation rates, and the above information, an approach to the control of fog and condensation can be established.

Fog occurs when cold outside air is injected into a warm, moist building and the resulting mixed air dry bulb temperature is below the dew point of the mixture. In cold climates, wintertime fog is a major source of lowered productivity in tankhouses. With process buildings operating under negative pressure, fogging can be difficult to control economically.

Elimination is a two-step problem based on the heat and moisture balance. The required temperature of the incoming air, to avoid this supersaturated condition, can be calculated. To ensure that air introduced is already close to its unsaturated equilibrium conditions, and further condensation is minimized, an efficient mixing system is required. Mixing plenums for make-up air with warm exhaust air offers a simple approach to this problem. Heat recovery benefits also make this solution attractive.

Surface condensation produces undesirable long-range impacts, as well. In an electrowinning cellhouse, condensation will be strongly acidic from the acid mist, making it a safety hazard and a major corrosion problem for building structures and equipment. In refinery tankhouses, the problem is confined to water vapour condensation, which is again a corrosion problem. In general, the condensation can be minimized by insulating the walls and roof to maintain, if possible, the inner skin surface above the air stream dew point. As the wet bulb temperature can exceed 90°F in the roof trusses of a refinery tankhouse in summertime, and approach saturation in the wintertime, there is no simple economically acceptable approach. In general, the better the insulation and the higher the make-up heat input to the building, the smaller the condensation rate. Proper selection of steel and siding coatings can give a cost-effective alternative to excessive heat input to the building. Where acid mist is present, no coating is wholly satisfactory, and the modern trend is toward the exclusive use of acid-resistant concretes and plastics in these areas.

Formulation of Ventilation Schemes

The first step involves controlling the source of contaminant emission, where 'contaminant' is defined to include process, heat, and moisture losses. As the problems associated with electrowinning and electrorefining are different, both process groups will be discussed individually.

In electrowinning of zinc, cathodes are typically lifted every 24 or 48 hours. As previously mentioned, use of foam on the cell surfaces appears to be practical. Because of the short deposition cycle common to zinc, any type of physical cover becomes a major operating nuisance and maintenance headache. While a Japanese plant has adopted this approach, no new North American plant has followed suit.

Floating plastic balls have also successfully reduced mist levels, and heat and moisture losses in a cellhouse. While the balls can also reduce a refinery process heat make-up requirement by up to 75%, they cannot effectively be contained within the tankhouse. The balls quickly spread throughout the plant, and cannot be recommended as practicable technology.

In electrorefining and in electrowinning of copper and nickel, where a cathode cycle is typically ten days, movable covers can be considered. These have been used with a noticeable degree of success in a major copper refinery. The design requirements of the cover, however, are not straightforward:

a) they must be light enough for two men to handle, typically a roll-up sheet.
b) they must be impermeable to moisture.
c) they must have a good thermal insulation value.
d) they must be non-combustible.
e) damage by shorts and hot spots should be only local, and not spreading.
f) if infra-red scanning is used, the cover should not interfere with the scan.

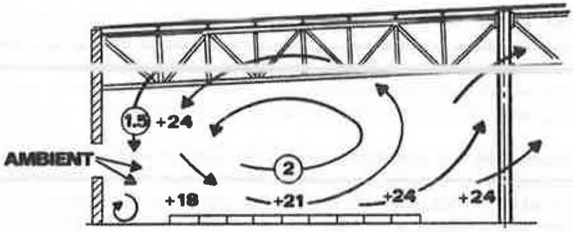
As a single material may not satisfy all these requirements, material selection involves compromises. The benefit of covers in improved conditions is marked. Labour and maintenance requirements are paid for by the process heating reduction.

Ventilation of the Building Space

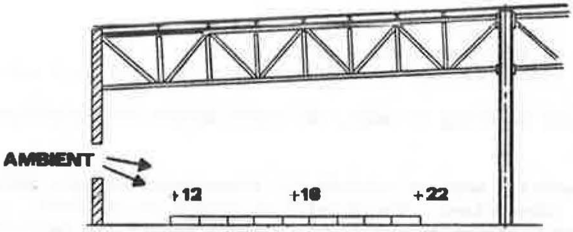
The objective of the ventilation scheme is to deliver acceptable air to all breathing zones and to sensitive equipment, where 'acceptable' means contaminated to levels below the design criteria. The condition at any location is governed by the degree of mixing that occurs between the contaminated air in the building and the incoming air. This degree of mixing is generally not amenable to direct calculation, because of the complexity of the flow fields within the building. There are strong buoyancy-induced flows from the hot liquid surfaces interacting with an imposed ventilation pattern. While it is a straightforward matter to calculate the contaminant levels on a "fully-mixed" basis, air volumes required to lower the "fully-mixed" levels to the design criteria are generally uneconomic. To minimize the air volume, and the system's capital and operating costs, proper location of air intakes and exhaust is critical. Large-scale recycles occur in buildings (Figure 2), and it is not possible to predict:

a) the boundaries of the recirculation zones
b) the contaminant levels within these zones.

As can be seen from Figure 2, the fresh air entering at the window is heavily contaminated by the time it reaches the first tanks, and is virtually ineffective by the time it reaches halfway across the aisle. This rapid contamination of fresh air must be avoided in the design; where it occurs it must be fully quantified to ensure it causes no problems.



WET BULB ELEVATION °F ⓥ VELOCITY ft./sec.



DRY BULB ELEVATION °F

Fig.2 TYPICAL FLOW RECYCLES AND TEMPERATURE ELEVATION IN A TANK HOUSE AISLE

The internal recirculating fields carry contaminated air into areas that would normally be expected to be clean. The behaviour of these recycles is only amenable to analysis and prediction in the simplest geometrical configurations, and extensive computer usage is required to obtain approximate solutions.

A simple and cost-effective approach to accurately predict the flow field involves fluid dynamic scale modelling. Required in this instance would be a small-scale replica of the building, and a full simulation of the internal flow field.

Fluid Dynamic Modelling

The underlying principle of modelling is that if certain non-dimensional parameters are the same in two separate flow systems, the flow fields are identical in their spatial distribution. This principle is used routinely in wind tunnel testing of aircraft, cars, and buildings, and in hydraulic testing of coastal dynamics, spillways, and hydraulic structures. The scale of the model and its working fluid are matters of convenience.

In buildings with powered ventilation, and a proper air distribution system design, the internal flow field will be independent of wind effects. For studies of this kind, the model scales have varied from a scale of 10:1 using air as a working medium, to 50:1 using water. With air-based models, the buoyancy input is properly scaled according to Densimetric Froude Number Criteria (Ref. 2,6), and the source of buoyancy used is heat via a heating element representing the tank surface geometry. Concentrations of contaminant throughout the model are then indicated by the temperature field within the model.

In the normally more convenient water-based models, the buoyancy of the tank and gas heat release is represented by the use of salt solutions of appropriate density. The salt concentration throughout the model can then be used as a measurement of the degree of contaminant dispersion within the model. The salt concentration can be measured by the conductivity or the specific gravity of solutions at a given location within the model, again depending on convenience.

Motion pictures and still photos are taken of the model flows using tracer dyes. These serve as documentation of a test on a ventilation configuration, and for detailed analysis of the contaminant transport.

For many buildings, especially those utilizing natural ventilation, the impact of wind effects on internal building flow is large. For a tankhouse, the lateral pressure gradient under wind conditions can exceed the vertical gradient, resulting in cross flows and total disruption of the flow fields. Analysis of ventilation under wind conditions can predict when these crossflows will occur. The impact on the internal flow field, however, cannot be predicted because of the complexity of the flow field. Where these effects have been investigated, a smaller scale model, typically 240:1, has been mounted in a water channel. The water channel velocity was regulated to effectively vary wind speed, and the model was rotated to simulate different wind directions. Upstream buildings were introduced to simulate their impact on the flow field. The consequent flow patterns, within the prime model building, were examined in detail for each variation in condition.

Model studies have been carried out on both electrowinning and electrorefining process buildings. These studies have also been used to examine designs of new buildings, and to successfully improve conditions in existing buildings.

Fluid dynamic scale modelling is a versatile tool for the ventilation designer. Provided the modelling is properly conceived, there will be no surprises when the selected ventilation scheme is implemented. Large numbers of ventilation schemes can be examined quickly and inexpensively.

Based on the input data for the plant, a series of ventilation options can be identified from experience, analysis, and good practice. These can then be checked and quantified for effectiveness in the model study, where 'quantification' means prediction of the contaminant concentration at any point of interest in the building. The flow arrangement and volume rates can be adjusted until the design goals within the building are met by the most cost-effective system.

At this point, the ventilation system parameters are set and detail design can proceed. As ventilation air requires heating in winter in northern climates, it makes sense to look at the availability of waste heat to reduce fuel costs or fuel dependence.

Potentials for Heat Recovery

Electrowinning

A simplified heat balance on an electrolytic zinc cellhouse is shown in Figure 3. Typically, 40 x 10^6 BTU/hr. is rejected in the spent acid cooling towers on a continuous basis. The peak make-up heat requirement for 800,000 ACFM of ventilation air on a -20°F day is 57 x 10^6 BTU/hr. to maintain 45°F in the cellhouse. The heat rejected in the cooling tower is a significant proportion of the maximum heat requirement.

The cost implications of the above comments are laid out in Table IV. It is clear that there is significant benefit to be obtained by recapturing this heat. Options available for heat reclaim are illustrated in Figure 4. There are two basic concepts: direct reintroduction of cooling tower exhaust air, and indirect transfer via a heat exchange system.

a) Direct Reintroduction of Cooling Tower Effluent. The key limits to this approach are mist control and moisture control. With 104°F electrolyte, the cooling tower exhaust can be around 95°F at 95% relative humidity. The maximum volume that can be used is determined by the required cellhouse dew point. A second limitation is set by the amount of mist recycled from the tower exhausts. Measurements on two currently-used demisters on electrolyte cooling towers indicate that levels below 1 mg/m^3 of acid mist in the exhaust are safely attainable. The percentage of cooling tower exhaust is limited by the total tankhouse TLV being acceptable. This mist recycle may be limited by local jurisdictions in some regions of the continent.

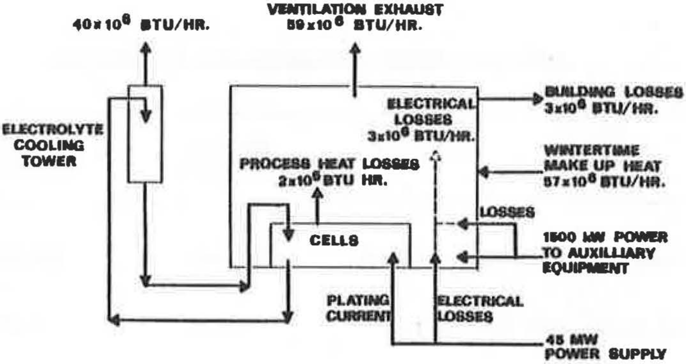
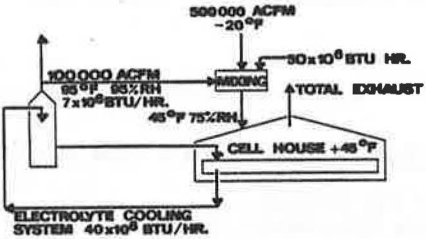


Fig.3 CELL HOUSE ENERGY BALANCE

a) DIRECT



b) INDIRECT

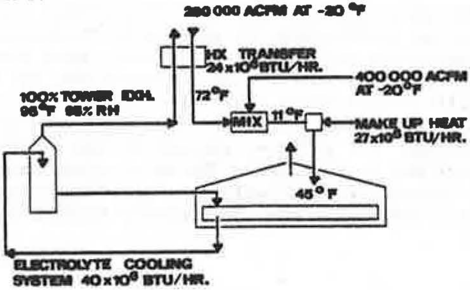


Fig.4 CELL HOUSE HEAT RECOVERY OPTIONS

Table IV. Economic Incentive for Heat Recovery

	No Heat Recovery	Heat Recovery
Ventilation exhaust volume (ACFM)	800,000	800,000
Annual degree days (re: 45°F)	6,000	6,000
Maximum heat recovery (%)	0	60
Maximum heat recovery (BTU/hr.)	0	24×10^6
Maximum heating requirement (BTU/hr.)	57×10^6	33×10^6
Annual heating requirement (BTU/yr.)	12×10^{10}	4.1×10^{10}
Fuel cost - propane (50¢/gallon)	$ 545,000 p.a.	$186,000 p.a.
Savings	-	$359,000 p.a.

b) Indirect Heat Exchange. Several forms of this are possible:

- gas to air heat exchange
- intermediate heat transfer fluids
- banks of heat pipes or heat wheels.

Gas to air heat exchange and intermediate heat transfer fluid cycles are not usually an economically or physically attractive approach because of the low temperature differences available. Heat pipes, however, with their very high specific heat transfer capacities, and their ability to operate effectively with small temperature drops, are attractive. Heat wheels have also been used successfully on low-grade heat recovery systems for mill buildings. For surfaces exposed to the cooling tower effluent, exotic materials may be required. The water condensation rate, however, will normally dilute the mist carry-over to non-agressive pH levels. Disposal of this condensate must be properly integrated with the plant water balance.

Economic Incentives

For a heat pipe system with 60% heat recovery from Table IV, the reduced fuel cost is \$359,000 p.a. based on heat into the ventilation air at \$5/million BTU's. Other pertinent costs for addition of heat recovery to an 800,000 ACFM system are:

Total Installed Cost Increment = $\$1.6 \times 10^6$

Operating Costs

Additional Power Cost \$0.03/kwh = \$ 40,000
Additional Maintenance (3% Inst. Cost) = \$ 48,000

Fuel Savings -359,000

Annual Operating Cost Reduction = \$271,000

$$\text{Cost Ratio} = \frac{\text{Capital Cost Increment}}{\text{Annual Operating Cost Saving}} = 5.9$$

As presented, the payback is not exceptionally good. Depending on local fuel costs, supply availability, and accounting procedures, though, this cost ratio can be reduced significantly.

For a system using direct reintroduction of cooling tower exhaust air, this cost ratio is reduced to less than 2.0. With a capital incremental cost of around \$350,000, this is an attractive system. The wisdom of this direct recycle with potential moisture and acid mist hazards, however, requires careful evaluation specific to the particular cellhouse.

Electrorefining

In electrorefining, there is a large heat loss to the refinery building (typically for copper 2 to 3×10^6 BTU/ton of cathode). For a 100,000 TPY tankhouse, this represents approximately 30×10^6 BTU/hr. lost into the building.

Because of temperature and moisture build-up, fresh air is required in winter. It is not, however, a heating problem of the same magnitude as in the zinc cellhouse. There is no acid mist generation, and fogging, which becomes the major concern, can be minimized by proper selection of make-up air temperature and supply concepts. Recently, work has been done using roof truss air to premix with cold dry outside air to eliminate fogging within the building. By use of such techniques, the need for make-up heat may be significantly reduced.

Concluding Remarks

The emphasis on workplace health and safety significantly adds to the problem of tankhouse ventilation design. To improve conditions in existing facilities, and for designing new facilities, new approaches to analytically insoluble building flow fields are required.

With a proper definition of contaminant generation rates, fluid dynamic scale modelling can solve building flow fields and concentration fields. This represents a powerful new tool for the designer. A new correlation for the prediction of mist evolution rates has been developed for zinc cellhouses. This correlation indicates that the future of foams for control of acid mist looks promising.

Heat recovery in cellhouse operation - not only technically feasible but also potentially economically attractive - deserves serious attention.

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