Specifying Steam Surface Condensers

by Elliot Spencer
Graham Mfg.Co., Inc., Great Neck, Long Island, N.Y.

Factors affecting condenser design and selection.
A typical air conditioning surface condenser specification is included.

THE FORMULA for determining the amount of surface required in a surface condenser is as follows:

Q = UA (LMTD) (1)

where

Q = Heat to be absorbed, Btuh = pounds per hour of steam times 950 Btu per pound;

U = Overall heat transfer rate, Btu per (hr) (sq ft) (F);

A = Surface required, sq ft;

LMTD = Log_e mean temperature difference between condensing temperature and cooling water.

No attempt will be made to go through a formal condenser selection. The procedure for condenser rating is amply covered in the publication of Heat Exchange Institute entitled, "Standards for Steam Surface Condensers."* Rather we shall attempt to discuss qualitatively the factors affecting selections and their effects on size and price.

Turbine Steam Rate

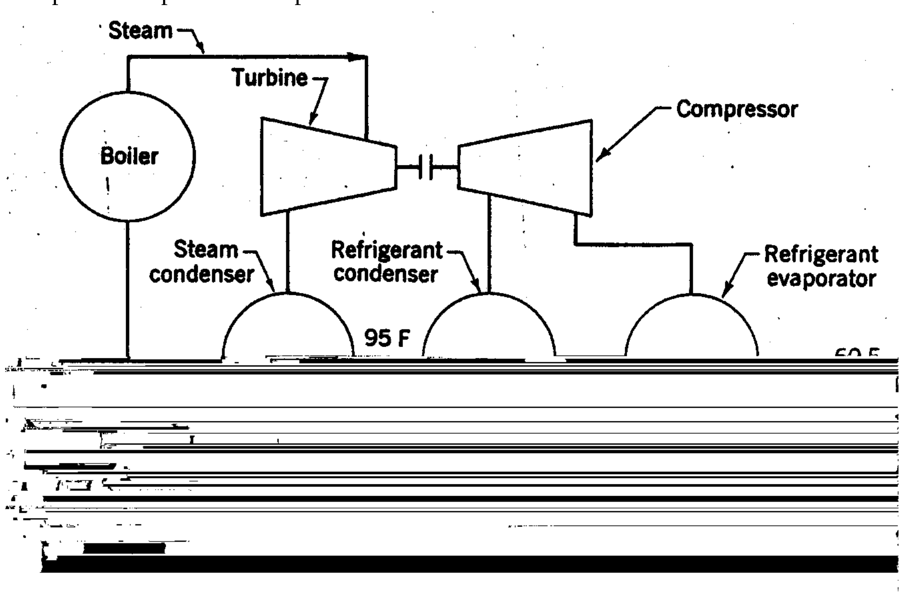
Turbine steam rate is usually expressed in pounds per hour of steam per brake horsepower and is commonly called the water rate. This water rate is a function of motive steam pressure and temperature, condensing temperature, or equivalent vacuum, and turbine efficiency. Specific information for a given turbine application can be obtained from the turbine manufacturer.

Generally speaking, on systems where the motive steam pressure is approximately 150 lb and the turbine is discharging to a vacuum of 26.inches of mercury (4 in. Hg absolute) , a steam rate of 14-16 lb per hr per bhp is economically feasible. Although greater efficiency is available at increased cost, utility costs for this type of installation seldom justify reducing the steam consumption by means of higher ef-ficiency turbines or lower condensing pressures. When special conditions are present, the specifying engineer may consider either of the above modifications to improve performance.

Condenser Vacuum

The vacuum produced in a steam condenser is that pressure corresponding to the temperature at which the steam condenses. This steam condensing temperature, in turn, is dependent upon the temperature of cooling water entering the condenser and the quantity of water available. The steam condensing temperature can get down to as low as 5F above the entering cooling water temperature, but in most air conditioning installations the differential is 20F, sometimes 10F, but seldom smaller, as the closer approach would require a costly amount of condenser surface.

In practice, cooling tower water is first used in the refrigerant condenser, where it rises about 10F and is then available for steam condensing. The great bulk of steam-driven cen-trifugal refrigeration systems operate with a steam condenser vacuum of approximately 4 in. Hg abs., which is equivalent to a condensing temperature of 125.4F. Thus, referring to Fig 1 and presuming that 85F cooling water is supplied to the system from the cooling towers, water temperature into the steam condenser is approximately 95F. Assuming a turbine steam rate of 14-16 lb per hr per bhp (bhp per ton of refrigeration is approximately 1) and a condensing water circulation rate of 3 gpm per ton of refrigeration, water rise on the steam condenser is also about 10F. Thus, the leaving water temperature approach is 20F(125F minus 105F).



This Standard is currently out of print, but a new edition is in preparation and will be available in the future from Heat Exchange Institute, 122 E. 42nd St., 'New York, N.Y. 10017.

If, on the other hand, we designed the steam condenser for 3 in. Hg. abs., which is equivalent to a condensing temperature of 115F for the same approximate water temperature rise, the approach would be 10F (115F minus 105F). Thus from Eq (1), because the log mean temperature difference is greater, we see that the condenser designed for 4 in. Hg abs. requires less surface than the one designed for 3 in Hg abs.

The foregoing example is an oversimplification. In practice, the steam rate of a turbine discharging at 4 in. Hg. abs. is somewhat higher than one discharging at 3 in. Hg. abs.

the tubes, a higher factor must be used. This holds true for both the refrigerant condenser and the steam condenser.

For most applications using clean cooling tower water, refrigeration condensers should be specified with a fouling factor of 0.0005 and steam surface condensers designed for an 85% clean tube coefficient. If the refrigerant fouling factor is increased, the surface condenser cleanliness factor should be increased by the same percentage. Thus, if the refrigerant condenser is specified as 0.001 vs. 0.0005, the corresponding cleanliness factor for the surface condenser is 70% clean vs. 85 % clean.

Steam Inlet Velocity

Velocity at the exhaust of the steam turbine is limited by National Electrical Manufacturers Association to 450 fps. Should the exhaust line from turbine to condenser be long, there can be excessive pressure drop in the vacuum line, which means that pressure at the condenser inlet is penalized by the pressure drop between turbine and condenser. Condenser manufacturers usually guarantee to maintain the specified vacuum at the inlet to the steam condenser. However, pressure drop between turbine exhaust and steam condenser must be calculated by the design engineer and compensated for by specifying that the condenser shall maintain a vacuum slightly below the vacuum at the exhaust of the turbine. A specification that calls upon the supplier to supply a specified steam consumption obviates this problem. Where a given velocity is used to determine the pressure drop, this should be stated in the specification so that it is not exceeded. In any event, velocities in excess of 450 fps should not be permitted.

Impingement plates should be provided below the condenser steam inlet to protect tubes from the effect of locally high inlet velocities and impingement of condensate. Steam inlet velocities should not exceed 400 fps and provision should be made based upon design experience in this field for proper vapor velocities within the shell.

Calculation of condenser heat load is based on the fact that steam entering the condenser has a value of approximately 950 Btu per lb. More precise calculations can be made if the specific turbine characteristics are available, but this figure is sufficiently accurate for the sizing of the cooling tower and condenser.

Space Limitations

Space considerations often influence the cost of a condenser. For example, if the surface condenser is limited in tube length, a multipass design may be required in place of a single-pass design. This results in a short, stubby unit, which is generally more expensive than a long, thin unit.

Specifications of head room limitations and permissible condenser tube length should take into consideration the distance beyond the tube sheets of the condenser required to allow removing tubes for replacement. Condensers must be mounted so that liquid level on the hotwell is sufficiently high to permit removal by condensate pumps. For air conditioning installations, the liquid level should be at least 5 ft above the inlet to the condensate pump and preferably 1 or 2 ft higher. This permits an economical pump selection.

Air Leakage

As both the exhaust of the steam turbine and the condenser are operating under a substantial vacuum, air is bound to leak into the system. This leakage occurs through the gland seals on the steam turbine and through minute holes in the piping connections associated with the surface condenser itself. Over a period of years, Heat Exchange Institute has determined the normal quantity of air that should leak through properly designed turbines and piping systems, and these are specified in their "Standards for Surface Condensers." Manufacturers have similarly standardized their ejector sets so that several standard sizes are available for specific air

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Materials of Construction

Materials used in construction of steam surface condensers are given in Table 1.

Use of copper alloy tube sheets in steam surface condensers with the accompanying requirement that tube sheets be bolted to the shell by means of collar bolts, is a carryover from marine practice. There is no reason why a steel tube sheet cannot be used, in view of the fact that the refrigeration condenser just upstream of the steam condenser uses this type of construction. When a steel tube sheet because it eliminates the possibility of a malfunction of this trap, which could bleed air back to the hotwell.

Pumps

Condensate pumps for air conditioning are customarily of the horizontal type, designed for approximately 4 1/2 - 5 ft net positive suction head (NPSH) and total dynamic heads of from 80-150 ft. Actual NPSH available for these pumps depends upon the physical location of the condenser. The discharge head is affected by where

Minimum Simplified Specification for
Steam Surface Condensers in
Air Conditioning Practice

Vacuum at inlet to steam condenser___________________
Steam flow to condenser, lb per hr___________________
Condenser water inlet temperature, F_________________
Condenser water gpm_______________________________
Permissible condenser water pressure drop, ft__________
Number of water passes_____________________________
(Single-pass for 26 in. of vacuum and two-pass for .27 in. Should be left up to supplier) .
Maximum water velocity, fps________________________
10 fps for cooling tower applications)
Tube diameter and gage_____________________________
(3/4 in. X 18 BWG)

Cleanliness factor_________________________________
(85% clean for cooling tower applications)
Waterbox design pressure___________________________
Water test pressure__________________________________
(1.5 times design pressure except for cast iron which is 5 Lb above design pressure)___________
Shell side design pressure ____________________________
(Full vacuum test to 20 Lb)
Steam pressure and temperature at ejector inlet___________
Condensate pump capacity, gpm _______________________
Condensate pump net positive suction head______________
Condensate pump discharge head_______________________
(Add pressure drop through inter- and aftercondensers and overboard valve to total system loss.)
Electrical characteristics of pump motors ________________

1. The steam condenser shall be of the shell and tube type, single or multipass, designed and constructed in accordance with Heat Exchange Institute (HEI) Standards, except as noted herein, and shall be suitable for the design conditions noted above. Condenser manufacturer shall demonstrate successful installations of similar equipment that has been in operation for at least__________(5 or 10) years.

2. Condenser shall have cast iron or steel waterboxes, steel tube sheets, steel tube supports, admiralty tubes and a steel hotwell complete with screen, strainer and hand-hole clean-out. Hotwell shall be of the vertical tank type, suitable for one-minute storage capacity.

3. Provision for tube expansion shall be made either by means of bowed tubes or shell side expansion joint. Covers of the waterboxes shall be removable without disturbing water piping. Connections shall be provided in the hotwell for ejector drain, condensate outlet, liquid level control bypass, fresh water startup, gage glass and high level water alarm. Connections shall also be supplied in the condenser shell for pump vent, vacuum gage, pressure gages to be located on waterboxes, an atmospheric relief valve and steam inlet from the turbine drive. Waterboxes shall be supplied with a plugged vent and drain and shall have flanged water connections. All vapor side flanges shall be 125 lb FF. Water side flanges shall be______________ lb (raised or flat face, depending upon pressure).

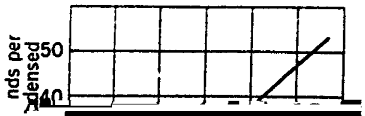
4. A single-element, two-stage ejector assembly, complete with internal interconnecting water and steam piping with surface inter- and after-condenser shall be provided. Ejector shall be cast iron. Ejector motive steam nozzles shall be stainless steel. The two-stage ejector shall be a self-contained package, complete with steam valves, interconnecting steam piping, steam strainer and interconnecting vapor piping, and shall be provided with mounting bracket so that ejector can be mounted directly on the surface condenser.

5. Condensate pumps shall be supplied in accordance with design conditions and shall be close coupled, single suction, enclosed impeller type with cast iron casings, bronze or cast iron impellers, stainless steel shafts, shaft seals suitable for the service, grease lubricated bearings and open drip-proof motors. Pump motor starters will be provided by others. Electrical characteristics will be as specified under _____________herein.

6. A hotwell gage glass shall be provided.

7. A steam inlet expansion joint shall be provided, sized to conform with the diameter of the turbine exhaust with corrugations. Expansion joint shall have copper or stainless steel bellows and shall be provided with a liner if steam velocity exceeds 300 fps.

8. An atmospheric relief valve shall be furnished, sized for protection in accordance with HEI Standards.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