Chapter 20

Operation, Maintenance, and Inspection (OM&I)

INTRODUCTION

This chapter is primarily concerned with operation, maintenance, and inspection issues as they apply to heat exchangers. These issues obviously vary with the type of heat exchanger under consideration. For the purposes of this chapter, the presentation will primarily address condensers since most of the exchangers reviewed up to this point in the text can be employed for condensation operations. In effect, this material can be applied virtually to all heat exchangers which for decades have been used in process operations—shell and tube, double pipe, air-cooled, flat plate, spiral plate, barometric jet, spray, etc.

Chapter contents include:

Installation Procedures

Operation

Maintenance and Inspection

Testing

Improving Operation and Performance

Note that the bulk of the material for this chapter has been drawn from the literature.[1,2]

INSTALLATION PROCEDURES

The preparation of a condenser or heat exchanger for installation begins upon receipt of the unit from the manufacturer. Condensers are shipped domestically using skids for complete units, and boxes or crates for bare tube bundles. Units are normally removed from trucks using a crane or forklift. Lifting devices should be attached to lugs provided for that purpose (i.e., for lifting of the complete unit as opposed to individual

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parts), or used with slings wrapped around the main shell. Shell supports are acceptable lugs for lifting, provided that the complete set of supports are used together; nozzles should not be used for attachment of lifting cables. Upon receipt of the unit, the general condition should be noted to determine any damage sustained during transit. Any dents or cracks should be reported to the manufacturer prior to attempting to install the unit. Flanged connections are usually blanked with plywood, masonite, or equivalent covers, and threaded connections are blanked with suitable pipe plugs. These closures are to avoid entry of debris into the unit during shipping and handling, and should remain in place until actual piping connections are made.

Clearance Provisions

Sufficient clearance is required for at least inspection of the unit or in-place maintenance. Inspection of heat exchangers requires minimal clearances for the following: access to inspection parts if provided, removal of channel or bonnet covers, and inspection of tube sheets and tube-to-tube sheet joints. If the removal of tubes or tube bundles in place is anticipated, provision should be provided in the equipment layout. Actual clearance requirements can be determined from the condenser setting plan.

Foundations

Heat exchangers must be supported on structures of sufficient rigidity to avoid imposing excessive strains due to settling. Horizontal units with saddle-type shell supports are normally supplied with slotted holes in one support to allow for expansion. Foundation bolts in these supports should be loose enough to allow movement.

Leveling

Heat exchangers should be carefully leveled and squared to ensure proper drainage, venting, and alignment with piping. On occasions, these units are purposely angled to facilitate venting and drainage, and alignment with piping becomes the prime concern.

Piping Considerations

The following guidelines for piping are necessary to avoid excessive strains, mechanical vibration, and access for regular inspection.

1. Sufficient support devices are required to prevent the weight of piping and fittings from being imposed on the unit.
2. Piping should have sufficient expansion joints or bends to minimize expansion stresses.

3. Forcing the alignment of piping should be avoided so that residual strains will not be imposed on any nozzles, if applicable.
4. If external forces and moments are unavoidable, their magnitude should be determined and made known to the manufacturer so that a necessary stress analysis can be performed.
5. Surge drums or sufficient length of piping to the condenser should be provided to minimize pulsations and mechanical vibrations.
6. Valves and bypasses should be provided to permit inspection or maintenance in order to isolate the condenser during periods other than complete system shutdown.
7. Plugged drains and vents are normally provided at low and high points of shell-tube sides not otherwise drained or vented. These connections are functional during startup, operation, and shutdown, and should be piped up for either continuous or periodic use and never left plugged.
8. Instrument connections should be provided either on condenser nozzles or in the piping close to the condenser. Pressure and temperature indicators should be installed to validate the initial performance of the unit as well as to demonstrate the need for inspection or maintenance.

OPERATION

The maximum allowable working pressures and temperatures are normally indicated on the heat exchanger's nameplate. These values must not be exceeded. Special precautions should be taken if any individual part of the unit is designed for a maximum temperature lower than the unit as a whole. The most common example is some copper-alloy tubing with a maximum allowable temperature lower than the actual inlet gas temperature. This is done to compensate for the low strength levels of some brasses or other copper alloys at elevated temperatures. In addition, an adequate flow of the cooling medium must be maintained at all times.

Condensers are designed for a particular fluid throughput. Generally, a reasonable overload can be tolerated without causing damage. If operated at excessive flow rates, erosion or destructive vibration could result. Erosion could occur at normally acceptable flow rates if other conditions, such as entrained liquids or particulates in a gas stream or abrasive solids in a liquid stream, are present. Evidence of erosion should be investigated to determine the cause. Vibration can be propagated by other than flow overloads (e.g., improper design, fluid maldistribution, or corrosion/erosion of internal flow-directing devices such as baffles). Considerable study and research have been conducted in recent years to develop a reliable vibration analysis procedure to predict or correct damaging vibration. At this point in time, the developed correlations are considered "state of the art," yet most manufacturers have the capability of applying some type of vibration check when designing an exchanger. Vibrations can produce severe mechanical damage, and operation should not be continued when an audible vibration disturbance is evident.

Startup

Exchangers should be warmed up slowly and uniformly; the higher the temperature ranges, the slower the warm-up should be. This is generally accomplished by introducing the coolant and bringing the flow rate to the design level and gradually adding the vapor. For fixed-tube-sheet units with different shell-and-tube material, consideration should be given to differential expansion of shell and tubes. As fluids are added, the respective areas should be vented to ensure complete distribution. A procedure other than this could cause large differences in temperature between adjacent parts of the unit and result in leaks or other damage. It is recommended that gasketed joints be inspected after continuous full-flow operation has been established. Handling, temperature fluctuations, and yielding of gaskets or bolting may necessitate retightening of the bolting.

Shut Down

Cooling down is generally accomplished by shutting off the vapor stream first and then the cooling stream. Again, fixed-tube-sheet units require consideration of differential expansion of the shell and tubes. Condensers containing flammable, corrosive, or high-freezing-point fluids should be thoroughly drained for prolonged outages.

MAINTENANCE AND INSPECTION

Recommended maintenance of exchangers requires regular inspection to ensure the mechanical soundness of the unit and a level of performance consistent with the original design criteria. A brief general inspection should be performed on a regular basis while the unit is operating. Vibratory disturbance, leaking gasketed joints, excessive pressure drop, decreased efficiency indicated by higher gas outlet temperatures or lower condensate rates, and intermixing of fluids are all signs that thorough inspection and maintenance procedure are required.

Complete inspection requires a shutdown of the condenser for access to internals and pressure testing and cleaning. Scheduling can only be determined from experience and general inspections. Tube internals and exteriors, where accessible, should be visually inspected for fouling, corrosion, or damage. The nature of any metal deterioration should be investigated to properly determine the anticipated life of the equipment or possible corrective action. Possible causes of deterioration include general corrosion, intergranular corrosion, stress cracking, galvanic corrosion, impingement, or erosion attack.

Cleaning

Fouling of exchangers occurs because of the deposition of foreign material on the interior or exterior of tubes. Evidence of fouling during operation is increased pressure drop and a general decrease in performance. Fouling can be so severe that tubes are completely plugged, resulting in thermal stresses and the subsequent mechanical damage of equipment.

The nature of the deposited fouling determines the method of cleaning. Soft deposits can be removed by steam, hot water, various chemical solvents, or brushing. Cooling water is sometimes treated with four parts of chlorine per million to prevent algae growth and the consequent reduction in the overall heat transfer coefficient of the exchanger. Plant experience usually determines the method to be used. Chemical cleaning should be performed by contractors specialized in the field who will consider the deposit to be removed and the materials of construction. If the cleaning method involves elevated temperatures, consideration should be given to thermal stresses induced in the tubes; steaming-out individual tubes can loosen the tube-to-tube sheet joints.

Mechanical methods of cleaning are useful for both soft and hard deposits. There are numerous tools for cleaning tube interiors: brushes, scrapers, and various rotating cutter-type devices. The exchanger manufacturer or suppliers of tube tools can be consulted in the selection of the correct tool for the particular deposit. When cutting or scraping deposits, care should be exercised to avoid damaging tubes.

Cleaning of tube exteriors is generally performed using chemicals, steam, or other suitable fluids. Mechanical cleaning is performed but requires that the tubes be exposed, as in a typical air-cooled condenser, or capable of being exposed, as in a removable bundle shell-and-tube condenser. The layout pattern of the tubes must provide sufficient intersecting empty lanes between the tubes, as in a square pitch. Mechanical cleaning of tube bundles, if necessary, requires the utmost care to avoid damaging tubes or fins.

TESTING

Proper maintenance requires testing of a condenser to check the integrity of the following: tubes, tube-to-tube sheet joints, welds, and gasketed joints. The normal procedure consists of pressuring the shell with water or air at the nameplate-specified test pressure and viewing the shell welds and the face of the tube sheet for leaks in the tube sheet joints or tubes. Water should be at ambient temperature to avoid false indications due to condensation. Pneumatic testing requires extra care because of the destructive nature of a rupture or explosion, or fire hazards when residual flammable materials are present. Condensers of the straight-tube floating-head construction require a test gland to perform the test. Tube bundles without shells are tested by pressuring the tubes and viewing the length of the tubes and back face of the tube sheets.

Corrective action for leaking tube-to-tube sheet joints requires expanding the tube end with a suitable roller-type tube expander. Good practice calls for an approximate 8% reduction in wall thickness after metal-to-metal contact between the tube and tube hole. Tube expanding should not extend beyond $\frac{1}{8}$ inch of the inner tube-sheet face to avoid cutting the tube. Care should be exercised to avoid over-rolling the tube, which can cause work-hardening of the material, an insecure seal, and/or stress-corrosion cracking of the tube.

Defective tubes can either be replaced or plugged. Replacing tubes requires special tools and equipment. The user should contact the manufacturer or a qualified repair contractor. Plugging of tubes, although a temporary solution, is acceptable provided that the percentage of the total number of tubes per tube pass to be plugged is not excessive. The type of plug to be used is a tapered one-piece or two-piece metal plug suitable for the tube material and inside diameter. Care should be exercised in seating plugs to avoid damaging the tube sheets. If a significant number of tube or tube joint failures are clustered in a given area of the tube layout, their location should be noted and reported to the manufacturer. A concentration of failures is usually caused by something other than corrosion (e.g., impingement, erosion, or vibration).

IMPROVING OPERATION AND PERFORMANCE

Within the constraints of the existing system, improving operation and performance refers to maintaining operation and original or consistent performance. There are several factors previously mentioned which are critical to the design and performance of a condenser: operating pressure, amount of noncondensable gases in the vapor stream, coolant temperature and flow rate, fouling resistance, and mechanical soundness. Any pressure drop in the vapor line upstream of the condenser should ordinarily be minimized. Deaerators or similar devices should be operational where necessary to remove gases in solution with liquids. Proper and regular venting of equipment and leakproof gasketed joints in vacuum systems are all necessary to prevent gas binding and alteration of the condensing equilibrium. Coolant flow rate and temperatures should be checked regularly to ensure that they are in accordance with the original design criteria. The importance of this can be illustrated merely by comparing the winter and summer performance of a condenser using cooling-tower or river water. Decreased performance due to fouling will generally be exhibited by a gradual decrease in efficiency and should be corrected as soon as possible. Mechanical malfunctions can also be gradual, but will eventually be evidenced by a near total lack of performance.

Fouling and mechanical soundness can only be controlled by regular and complete maintenance. In some cases, fouling is much worse than predicted and requires frequent cleaning regardless of the precautions taken in the original design. These cases require special designs to alleviate the problems associated with fouling. For example, a leading PVC manufacturer found that carryover of polymer reduced the efficiency of its monomer condenser and caused frequent downtime. The solution was providing polished internals and high condensate loading in a vertical down flow shell-and-tube condenser. In an another example, a major pharmaceutical intermediate manufacturer had catalyst carryover to a vertical downflow shell-and-tube condenser which accumulated on the tube internals. The solution was to recirculate condensate to the top of the unit and spray it over the tube-sheet face to create a film descending down the tubes to rinse the tubes clean.

Most condenser manufacturers will provide designs for alternate conditions as a guide to estimating the cost of improving efficiency via other coolant flow rates and temperatures as well as alternate configurations (i.e., vertical, horizontal, shell side, or tube side).

REFERENCES

1. W. Connery, et al., *Energy and the Environment*, Proceedings of the Third National Conference, AIChE, 1975, 276–282.
2. L. Theodore and A. J. Buonicore (editors), *Air Pollution Control Equipment*, Chapter 6 (W. Connery), Theodore Tutorials (originally published by Prentice-Hall), East Williston, NY, 1992.