

DEP SPECIFICATION

AIR-COOLED HEAT EXCHANGERS – SELECTION AND APPLICATION

DEP 31.21.70.10-Gen.

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DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the selection and application of air-cooled heat exchangers (commonly referred to as air-cooled heat exchangers) for refining, chemical, petro-chemical, and natural gas processing industries.

NOTE: Design, manufacture and supply of air-cooled heat exchangers is covered in DEP 31.21.70.31-Gen.

This DEP is not intended to be applied to “A” frame, “V” frame, or “roof” type air-cooled heat exchangers, or to air-cooled heat exchangers provided as part of a packaged gas compressor system, where inclined bundles and a single electric or engine driven fan is often used.

This DEP specifies thermal, mechanical, and structural design requirements for air-cooled heat exchangers, and correspondingly assists the design team/designer of either the Principal or the Contractor. The requirements direct selection/design of cost effective heat exchangers that are consistent with the service conditions, intended design life, and criticality of the application.

In this DEP it is premised that the user has familiarity with DEP 31.21.70.31-Gen. and ISO 13706, which are primarily intended for use by the Manufacturer/Supplier.

This DEP provides information typically required for a bid requisition. It is, therefore, not intended for air-cooled heat exchanger Manufacturers.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 – Application of Technical Standards.

This is a revision of the DEP of the same number dated February 2011; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorization to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (5).

1.5 SUMMARY OF CHANGES

This DEP is a revision of the DEP of the same number dated February 2011. This is a major revision and as such, the changes are too numerous to list here.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
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Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. DESIGN

2.1 INTRODUCTION

1. The basic expectation is that the Contractor will provide the process and mechanical definition for the application, and the Manufacturer will provide the complete thermal design and guarantee. In some cases, the initial thermal design may be provided by the Contractor.
2. Items listed in the Air-Cooled Heat Exchangers Checklist (see Annex B, ISO 13706) are covered in DEP 31.21.70.31-Gen., except for drawing requirements. The Contractor shall specify the number of copies of drawings, data, etc., required for the project.
3. When providing specifications for air-cooled heat exchangers and filling in data sheets, the items in ISO 13706 marked with a bullet (•), shall be provided by the Contractor; Standard Form DEP 31.21.70.81-Gen. should be utilized for this purpose.
4. The "design synopsis checklist" is provided in DEP Standard Form 31.21.70.82-Gen. It is provided as a guide for the Contractor in understanding and specifying overall design requirements. It covers equipment integrity, process service, arrangement and process control considerations. This is considered a "living" document which will be completed and reviewed as the design develops. The design synopsis checklist shall be appended to the data sheet through the design/ specification stage of the project. It shall be retained by the Contractor and included with the equipment records/data book for the project. This document is not intended for the Manufacturer.
5. Decisions related to the design class performance categories for air-cooled heat exchangers are intended to be made by the Principal in the project "Define" phase and detailed in project scope defining documentation e.g., equipment basic design engineering package (BDEP), air-cooled heat exchanger data sheet, air-cooled heat exchanger checklist, project specific specifications, etc.
6. This DEP is generally written for Design Class 2 / 3 facilities, with options identified basis design class where appropriate. When projects opt not to implement the design class practice, options set forth within this DEP based on design class shall default to Design Class 3 selection unless otherwise directed by the Principal.

2.2 PROCESS SPECIFICATION AND GENERAL DESIGN

2.2.1 General

Air-cooled heat exchangers are generally appropriate for services with larger duties, services at elevated temperatures that could cause excessive scaling if water cooled exchangers were used, and where water use for cooling is restricted.

1. Data sheets and curve-specified data shall represent the actual exchanger design conditions. The heat duty specified should be consistent with the flows and temperatures specified. If excess flow or heat duty is required, the resulting temperatures and flows shall also be specified.
2. All expected operating scenarios/conditions shall constitute separate alternative design cases and shall be identified by separate data sheets. Predictable upset conditions and full range of flows (turn-down) shall also be specified.
3. The entire service cooling duty should be achieved in one type of equipment, e.g., air-cooled heat exchanger or water-cooled exchanger, rather than dividing the duty between air and water cooled exchangers when the cold end approach to the ambient air temperature is 11°C (20°F) or more. Cooling by water-cooled exchangers alone may only be considered when the resulting skin temperatures against cooling water are acceptable.
4. The option of applying a downstream water-cooled exchanger to handle at least part of the duty should be evaluated when the cold end approach drops below 11°C (20°F).

For such an arrangement, the following break temperatures should normally be considered:

- a. 25°C (45°F) above the ambient air temperature for liquid or vapour cooling services;
- b. 40°C (70°F) above the ambient air temperature for condensing services.

2.2.2 Stream property considerations

1. Stream physical properties and data shall be provided as specified in the following paragraphs to allow design and analysis using Shell's preferred methods.
2. Transport properties for well-known components such as air or water, do not need to be specified.
3. For single phase cooling, transport properties (viscosity, density, thermal conductivity, specific heat) shall be provided at the inlet and exit conditions.
4. For liquid streams with a viscosity > 10 cP, a viscosity curve with intermediate temperatures shall be provided from the inlet temperature down to a temperature equal to the minimum ambient air temperature for units without warm air recirculation. For units with warm air-recirculation, the viscosity curve shall extend to the minimum specified plenum temperature.
5. For condensing streams, transport properties shall be provided for each phase at the inlet, outlet, and several intermediate temperature points, such that purely-interpolation-based errors do not exceed 5%.
 - a. The transport properties shall be based on the total composition of each phase including water, air and/or steam when these components are part of a homogeneous phase.
 - b. Liquid properties at the dew point and vapour properties at the bubble point should be included when such points occur within the air-cooled heat exchanger. If water is present, the water dewpoint at the operating pressure shall also be specified.
 - c. Additionally, plots of heat release (or total stream enthalpy), weight fraction vapour, percent (by weight) of the second liquid phase (if present) and vapour molecular weight vs. temperature at inlet pressure and the inlet pressure minus the allowable pressure drop shall be provided.
 - d. The above information shall be calculated under the assumption of thermodynamic equilibrium.
6. If condensate has immiscible components, liquid properties shall be specified separately and completely for each liquid phase.
7. If liquid disengages from vapour in an amount sufficient to alter vapour-liquid equilibrium implicit in (item 5) above, differential condensation plots of percent (weight) vapour and vapour molecular weight should be provided when requested by the air-cooled heat exchanger design engineer, and considered in the thermal and hydraulic performance design.
8. The nature, size (e.g., microns) and quantity (in wt% or ppm) of solids in the stream such as silt, sand, fines, catalyst fines, etc., shall be specified on the equipment data sheet when applicable. This is particularly important for design of pressure equipment in upstream environments (e.g., tailings, slurry services in mining, froth treatment facilities) to prevent plugging and/or erosion. Where the size distribution and shape of the solids are known, this information shall also be provided on the data sheet.

9. The quantity of free water (wt% or ppm) in the stream shall be defined on the equipment datasheet as well as any other compounds (e.g., ammonia, H₂S, chlorides, etc.) which when combined with water may form a corrosive environment.
10. Specifying the water content in the stream is critical to ensure that air-cooled heat exchangers are designed adequately for freeze protection and that this consideration is taken into account for design of piping systems/valves against freezing.
11. The Contractor SHALL [PS] specify if the stream is sour or has wet H₂S.
12. The Contractor shall clearly specify the sulphide stress cracking (SSC), hydrogen blistering, hydrogen induced cracking (HIC), stress-oriented hydrogen induced cracking (SOHIC), and carbonate cracking severity ratings of the stream on the equipment data sheet, as determined in accordance with DEP 30.10.02.15-Gen. or DEP 30.10.02.17-Gen., as may be applicable.
13. The freezing point, the pour point, the wax point, the dew point (if condensation may result in increased corrosion), the hydrate formation point, or any other temperature that can create operating difficulties for an air-cooled heat exchanger SHALL [PS] be indicated on the process data sheet if any of these critical process temperatures are greater than the minimum ambient temperature for the location in which the air-cooled heat exchanger will be installed. All that apply shall be specified.

2.2.3 Hydrogen and toxic service considerations

1. The Contractor shall specify on the air-cooled heat exchanger data sheet any exchangers that are subject to hydrogen service along with the hydrogen partial pressure. Hydrogen service is defined as any service in which the hydrogen partial pressure is greater than 700 kPa absolute (100 psia) at any temperature.
2. The Contractor SHALL [PS] specify on the air-cooled heat exchanger data sheet any exchangers that are subject to very toxic service. Very toxic substances are those that are considered as very hazardous for the environment or human health, as specified in DEP 01.00.01.30-Gen.

2.2.4 Alternate operating mode considerations

1. Alternate operating modes, such as low process flow at low ambient air temperature, upsets with high process inlet temperatures $\nless 150\text{ }^{\circ}\text{C}$ [$\geq 300^{\circ}\text{F}$]), steam-out, loss of fans due to power failure, temperature bake-out, etc. SHALL [PS] be specified on the data sheet. This information should be provided on separate process data sheets along with physical properties, condensing curves, etc., in addition to the defined normal operating cases. This information is needed to ensure an adequate mechanical design.
2. Abnormal flows and/or temperature conditions that are expected to impose either additional duty requirements or require additional heat transfer surface area or air flow shall be specified.
3. Alternate operating modes shall not be dismissed from analytical review simply because they are lower heat duty cases.

2.2.5 Fouling considerations

1. Tube-side fouling resistances or design margins should be specified based on DEP 20.21.00.31-Gen., plant experience for a specific service, project specific information, or licensor requirements.
 - a. When no data or experience for fouling resistance is available, TEMA recommended values for the most similar fluid may be used.
 - b. Through the course of detailed design, if the effective resistance for fouling is found to be greater than 30% of the overall heat transfer resistance, the thermal design engineer shall consult with the Principal to determine if the fouling factor or margin may be reduced accordingly to optimize the design.

2. External fouling factors should not be applied. A sufficient allowance on air side static pressure loss shall be applied for the selection of the fan and motor, in addition to any other air flow margins, to adequately address the needs of a particularly dirty environment (dust, pollen, seeds, cooling tower drift, etc.) in lieu of the use of an external fouling factor. Refer to (2.4.2 Item 2) and (3.8.1 Items 5, 6, and 7) for further information.

Fouling of the external surface usually affects the resistance to air flow with little effect on heat transfer coefficient. The performance of the cooler suffers due primarily to reduced air flow and resulting temperature difference so imposition of a thermal resistance (fouling factor) is not realistic.

3. Locations that are susceptible to environmental fouling should consider the inclusion of lint/bug screens to minimize air-side fouling.

2.2.6 Ambient condition considerations

1. The design air dry bulb temperature shall account for both the specific geographical location and localized plant influences.
2. Air-cooled heat exchangers in non-critical process services shall base their inlet design air temperature on the ambient dry bulb temperature that is equalled or exceeded 2% of the time (approximately 175 hours per annum). An allowance required for surroundings and installation factors shall be added to this base temperature.
 - a. For minimum service design (Design Class 1 Capacity) facilities, no allowance should be added.
 - b. For general service design (Design Class 2 Capacity) facilities, this allowance should be 2°C (4°F).
 - c. For robust service design (Design Class 3 Capacity) facilities the allowance should be 3°C (6°F).
3. Air-cooled heat exchangers in rundown service, and other services that can take advantage of the normal diurnal temperature variation, may use the ambient dry bulb air temperature determined by (item 2) above less 3°C (6°F).
4. Where water trim cooling is used downstream of air-cooled heat exchangers, consideration may be given to a reduction in the summer ambient air design temperature by 3°C (6°F). It is not recommended to reduce the air design temperature for Type 3 winterized air-cooled heat exchangers defined as being in a "critical process service" in this same situation as they are more prone to hot air recirculation in summer, because of larger air approach velocities and potential leakage of hot air through the recirculation louvers.
5. The design minimum ambient air temperature SHALL [PS] be provided and properly addressed in the selection of the temperature control method to avoid freeze point or dew point (if corrosive) and in mechanical design and fabrication. The latter shall be assessed if duty is allowed to vary with ambient temperature.
 - a. In such cases, the process temperature range can become large and the need for split header construction, to allow the thermal expansion differential between passes, shall be analyzed with consideration of the increased cooling capacity during low ambient temperatures.
 - b. In addition, the pressure drop and heat transfer of highly viscous services may be significantly impacted and shall be properly assessed and accounted for in the design.

2.2.7 Critical process service considerations

1. Critical process services are defined as services which would constitute a problem with respect to safeguarding, technical integrity of downstream equipment, tanks, etc., production capacity, or product quality, if the air-cooled heat exchanger design outlet temperature is exceeded during normal operation.
2. The process data sheet and design synopsis checklist shall clearly indicate if a service is considered "critical" from this perspective. Some typical examples of critical process services are as follows:
 - a. Air-cooled heat exchangers in cooling-sensitive services, when not followed by a water-cooled trim cooler, whose performance can directly affect the facility capacity, throughput, technical integrity or product quality;
 - b. Air-cooled heat exchangers used for light hydrocarbon streams such as C5/C6 or light straight run naphtha/depropanizer bottoms streams which must be rundown a safe margin below tank vapour pressure limits; typically 5°C (9°F);
 - c. Air-cooled heat exchangers used for jet fuel or other low conductivity products which must be rundown at a safe margin below flash point.
3. Air-cooled heat exchangers in critical process services shall base the inlet design air temperature on the ambient dry bulb temperature that is equalled or exceeded one percent of the time (approximately 90 hours per annum), plus a 3°C (6°F) allowance, regardless of Design Class, to assure proper operation.
4. Air-cooled heat exchangers shall not be used for services where the required cold end approach to the ambient air temperature is less than 6°C (10°F), or less than 11°C (20°F) for critical process services.

2.2.8 Natural draught duty considerations

1. During the loss of air-cooled heat exchanger fans, DEP 80.45.10.11-Gen. specifies that, for the purposes of relief valve design, the natural draught duty of an air-cooled heat exchanger may be assumed to be 5 % of design. However, a natural draught duty of greater than 5 % can be assumed if supported by analysis.
2. The Manufacturer may be required to predict the natural draught performance with design ambient air temperature when necessary to support this analysis, provided the air-cooled heat exchanger is not equipped with fail closed louvers and/or that the air-cooled heat exchanger is not a column overhead condenser that would flood during such an upset due to a loss of reflux.

2.2.9 Energy efficiency considerations

1. For projects incorporating energy efficiency targets, the Manufacturers should optimise their design relative to equipment costs and power consumption.
2. The power cost factors and formula to be used for the design optimization and evaluation shall be provided by the Contractor.
3. The Manufacturers should be asked to quote the additional (installed) cost of velocity recovery stacks and the horsepower required with and without velocity recovery:
 - a. For induced draught units on projects or locations with high electric power costs, particularly where maximum natural draught duty to limit flare losses during power failures is desired
 - b. If the fan velocity pressure exceeds 7.6 mm (0.3 in) of water column
4. Velocity recovery stacks should normally not be credited with pressure recovery greater than 67% of theoretical recovery.

2.3 THERMAL DESIGN

2.3.1 General

1. The thermal design for air-cooled heat exchangers is normally performed by the Manufacturer. During the evaluation of the Manufacturer's bids the Contractor shall check rate the Manufacturer's thermal designs.
2. The Manufacturer's design shall be adjusted, if necessary, to meet the calculation requirements.
3. The thermal and hydraulic design of air-cooled heat exchangers shall be based on design methods that have been proven in practice. In this respect, the design procedures and computer programs published by Heat Transfer Research Inc. (HTRI) or Aspen+ (the former Heat Transfer and Fluid Flow Services (HTFS) software), or UNISIM shall be used.
4. Discrepancies in the performance prediction results between different design methods shall be referred to the Principal for resolution.
5. Any special requirements assumed for the thermal design, e.g., irregular pass layouts or tube inserts, shall be recorded appropriately on the data sheets and/or equipment sketches.
6. The air-cooled heat exchanger rating files shall be turned over to the Principal at the conclusion of the project.
7. In the case of a proprietary design, the Manufacturer shall contact the Principal to agree on the calculation method and the degree of responsibility.

2.3.2 Exchanger configuration

1. Air-cooled heat exchangers shall not be less than three (3) tube rows deep and shall not have nominal air face velocities less than 2.0 m/s (400 ft/min).
2. Unless otherwise specified, the air-cooled heat exchanger type shall be forced draught to facilitate re-tubing and for ease of access to fans, fan bearings as well as to minimize the exposure of the rotating parts to high temperature.
3. Forced draught arrangements shall be used when the maximum process inlet temperatures equals or exceeds 150°C (300°F).
4. Air-side design Type 1 or 2 coolers with process inlet temperatures less than 150°C (300°F) where rain on the cooler may upset the process system control, should normally be specified as induced draught. For less critical services, the installation of a 'false plenum' above forced draught coolers may be considered to limit the impact of rainfall on the tube bundle.
5. If the outlet air temperature can exceed the limits for fan, bearings, grease, and appurtenances under any planned operating case including turndown, forced draught coolers should be applied.
6. Induced draught coolers are preferred for services that require a cold end and/or hot end temperature approach of 11°C (20°F) or less (15°C (27°F) in process critical services) and have process inlet temperatures less than 150°C (300°F). If outlet air temperature can exceed the limits for fan, bearings, grease, and appurtenances forced draught coolers shall be applied.
7. Induced draught coolers are preferred for locations subject to significant solar radiation effects. Where forced draught coolers are necessary due to process inlet or air outlet temperatures, the addition of a 'false plenum' may be considered to limit solar exposure.
8. Air-cooled heat exchangers requiring a Type 3 air-side design shall be specified as forced draught only.
9. Use of other types of air-cooled heat exchangers, such as A-frame, natural draught, vertical fan and/or bundle, and wetted surface air-cooled heat exchangers may be

considered where economically and technically feasible, but require approval of the Principal.

10. Single-pass (non-A frame) air-cooled steam condensers shall not be used, to avoid the potential for back-flow of steam from the outlet end of the upper rows into the outlet end of the lower tube rows as this can result in inert blanketing and increased corrosion.
11. The design of combination air-cooled heat exchangers that serve two or more bundles in different process services requires specific approval from the Principal, and shall not be used when more than one service requires active and close process outlet temperature control ($\pm 3^{\circ}\text{C}$ [5.0°F]).

2.3.3 Tube bundle design

1. If a tube is specified or purchased to a minimum wall specification, the tube thickness used for thermal and hydraulic purposes shall be 1.1 times the minimum wall thickness. This is to simulate the actual supplied tube thickness.
2. The minimum in-tube velocities for single phase (non-erosive) liquid streams shall be as specified in Table 1. For erosive streams, the Principal shall be consulted.

Table 1 Minimum in-tube velocities

Fouling Characterization	Fouling Factor		Velocity (m/s)	Velocity (ft/s)
	$\text{m}^2\text{-K/W}$	$^{\circ}\text{F h ft}^2/\text{Btu}$		
Very Low	≤ 0.00009	≤ 0.0005	1.0	3.0
Low	≤ 0.00026	≤ 0.0015	1.0	3.0
Medium	≤ 0.00052	≤ 0.003	1.5	5.0
High	≤ 0.0012	≤ 0.0068	2.0	6.5
Severe	> 0.0012	> 0.0068	2.2	7.2

3. The maximum in-tube velocities shall be in accordance with the following:
 - a. For non-erosive liquids, the velocity head shall be calculated using the equivalent maximum water velocities as specified in DEP 20.21.00.31-Gen. for the different tube materials.
 - b. For dry non-erosive gases, no specific maximum tube velocity limits apply.
4. Where specific maximum velocities apply due to process service or metallurgy (e.g., amine service, wet sour service in some metallurgies, etc.), these limits shall be indicated on the exchanger data sheet.
5. Consideration should be given to special provisions and/or devices to prevent erosion of the tube ends for saturated vapours and two-phase fluids, if the velocity head (ρV^2) in the tubes exceeds $8,930 \text{ kg/m-s}^2$ ($6,000 \text{ lb/ft-s}^2$).
 - a. In ρV^2 , V is the linear velocity in m/s (ft/s) and ρ is the fluid density in kg/m^3 (lb/ft^3).
 - b. For two-phase fluids, the homogeneous velocity should be used.
6. Tube bundle designs with partial rows per pass at the inlet (hot) end of the process fluid flow path may require split headers or other methods of restraint relief as necessary to prevent bowed tubes, roll leaks, and air flow restriction due to unequal thermal expansion of tube rows. The analytical review shall be included with the mechanical design calculation documentation.
7. Tube inserts, such as twisted tape turbulators, static mixers or similar devices, may only be used with the approval of the Principal. When applied, consideration should be given to the use of a removable cover plate header design in these services within the design pressure and temperature limits of such header boxes.