1.0 Executive Summary

This report provides a comprehensive technical assessment regarding the feasibility of utilizing Solvent Deasphalted (SDA) pitch, a byproduct from UOP SDA units, as a feedstock for asphalt production, thereby increasing coker capacity for surplus vacuum residue. Concurrently, it addresses the critical engineering considerations for the design, construction, and operation of a large-scale (greater than 600 m^3) heated storage tank for this SDA pitch.

The analysis indicates that while SDA pitch in its neat form is generally unsuitable for direct use as paving-grade asphalt due to its inherent hardness and brittleness [1], it can be transformed into a marketable asphalt product through carefully controlled blending with suitable flux oils or softer bituminous components.[2] Success in this venture is contingent upon meticulous product formulation to meet stringent international and regional asphalt quality standards (e.g., ASTM, AASHTO, EN). The selection of appropriate flux oils and the assessment of blend compatibility are paramount to prevent issues like asphaltene precipitation and ensure long-term product stability.

The storage of SDA pitch, particularly at elevated temperatures (150-200°C) required to maintain fluidity, presents significant engineering challenges. The design of large-capacity storage tanks must adhere to rigorous industry codes, primarily API 650, with specific attention to Appendix M for elevated temperature service.[5] This includes judicious material selection to counteract potential high-sulfur corrosion, appropriate corrosion allowances, robust heating systems (hot oil systems being generally favored for efficiency and safety at high temperatures), effective thermal insulation to minimize heat loss and manage Corrosion Under Insulation (CUI), and sound foundation design accounting for thermal loads on soil and concrete. Furthermore, specialized mixing systems are necessary to maintain homogeneity and prevent sludge accumulation in the viscous pitch. Comprehensive safety systems for overfill protection, venting, and fire protection are non-negotiable.

The decision to proceed with selling SDA pitch as asphalt is technically complex. It necessitates a thorough techno-economic evaluation, weighing the costs of pitch modification and specialized storage infrastructure against the benefits of increased coker throughput and potential revenue from asphalt sales. A phased approach, starting with laboratory-scale blend development and detailed engineering studies, is recommended to mitigate risks and optimize the project's viability. The long-term integrity and operational reliability of the storage facility must be a central focus throughout the design and execution phases.

2.0 Asphalt Product Standards and Specifications

The successful marketing of asphalt derived from SDA pitch necessitates strict adherence to globally recognized quality standards and specifications. These standards, promulgated by various international and regional bodies, define the physical and performance characteristics that asphalt products must meet to be accepted for use in paving and other applications. A thorough understanding of this regulatory landscape is crucial for product development, quality control, and market access.

2.1 Overview of International Standards Bodies

Several organizations are pivotal in developing and maintaining asphalt standards worldwide:

- **ASTM International (formerly American Society for Testing and Materials):** ASTM is a globally recognized leader in the development and delivery of voluntary consensus standards. Their standards are used around the world to improve product quality, enhance health and safety, strengthen market access and trade, and build consumer confidence.[7] ASTM's standards cover a wide range of materials and industries, not solely focusing on transportation like AASHTO.[9]
- **AASHTO (American Association of State Highway and Transportation Officials):** This organization develops standards and specifications primarily for the design, construction, and maintenance of highways and transportation systems in the United States.[7] The AASHTO Subcommittee on Materials (SOM) is responsible for maintaining standards for various materials, including asphalt binders (managed by Technical Section 2b) and asphalt mixtures (Technical Section 2c).[9] Efforts are often made to harmonize AASHTO standards with those of ASTM International.[9]
- **EN (European Norms):** These standards are developed by the European Committee for Standardization (CEN) and are mandatory for use in European Union member states, facilitating trade and ensuring product compatibility within the European market. For bitumen and asphalt, EN standards are critical for market acceptance.[10] Key standards include EN 12591 for paving grade bitumens [11], the EN 13108 series for asphalt product specifications, and the EN 12697 series for test methods.[13] CEN/TC 336 is the technical committee responsible for asphalt and bituminous binders.[14]

2.2 Key Asphalt Grading Systems and Associated Standards

Asphalt binders are classified using various grading systems, each with its own set of standard test methods and specifications. The choice of grading system often depends on regional preferences, climatic conditions, and specific performance requirements.

- **Penetration-Graded Asphalt:** This is a traditional method that classifies asphalt based on its hardness at a standard temperature (25°C). The penetration test measures the depth, in tenths of a millimeter (dmm), that a standard needle under a 100-gram load penetrates the asphalt sample in 5 seconds.[10] A higher penetration value signifies a softer asphalt, while a lower value indicates a harder grade.[15]
    - **Relevant Standards:**
        - **ASTM D946:** *Standard Specification for Penetration-Graded Asphalt Cement for Use in Pavement Construction*. This standard defines the physical and chemical properties, such as penetration, viscosity, ductility, and flash point, along with the test methods used to measure these properties.[8]
        - **EN 12591:** *Bitumen and bituminous binders - Specifications for paving grade bitumens*. This European standard specifies requirements for various penetration grades (e.g., 35/50, 50/70, 160/220) including their penetration limits, softening points, and flash points.[11]
    - **Common Grades and Applications:** Typical penetration grades include 40/50 (hard, suitable for hot climates and heavy traffic), 60/70 (medium-hard, widely used for general road construction and roofing), 80/100 (softer, for cooler climates or lighter traffic), and 160/220 (very soft, for cold climates or special applications).[10] The selection of a specific penetration grade is primarily dictated by the prevailing climatic conditions and the expected traffic loading of the pavement.[10]
- **Viscosity-Graded Asphalt:** This system classifies asphalt binders based on their viscosity (resistance to flow) at specified temperatures, typically 60°C (140°F) and sometimes 135°C (275°F). Grading by viscosity provides a more direct measure of the binder's consistency at high service temperatures, which is particularly relevant for predicting rutting resistance in hot climates and for regions with significant temperature variations.[10]
    - **Relevant Standard:**
        - **ASTM D3381/D3381M:** *Standard Specification for Viscosity-Graded Asphalt Cement for Use in Pavement Construction*. This specification offers three sets of limits for different viscosity grades, such as AC-2.5 to AC-40 (based on original asphalt viscosity at 60°C) and AR-1000 to

AR-16000 (based on aged residue viscosity at 60°C). It includes requirements for viscosity at 60°C and 135°C, penetration, flash point, solubility, and ductility after the Thin-Film Oven Test (TFOT), which simulates short-term aging during mixing and construction.[17]

- **Performance-Graded (PG) Asphalt:** This is a more modern and comprehensive grading system developed under the Strategic Highway Research Program (SHRP). PG binders are characterized by their expected performance over a wide range of pavement temperatures and aging conditions.[18] The PG system addresses specific pavement distresses such as rutting at high temperatures, fatigue cracking at intermediate temperatures, and thermal cracking at low temperatures.[19] A PG binder designation, for example PG 64-22, indicates the average 7-day maximum pavement design temperature (in °C) and the minimum pavement design temperature (in °C) that the binder is designed to withstand.[18]
    - **Relevant Standards:**
        - **AASHTO M 320:** *Standard Specification for Performance-Graded Asphalt Binder*.[18]
        - **ASTM D6373:** *Standard Specification for Performance Graded Asphalt Binder*.[8]
    - **Key Performance Tests:** A suite of laboratory tests is employed to classify PG binders, simulating conditions the binder will experience throughout its service life. These include:
        - Flash Point Test (AASHTO T 48 / ASTM D92)
        - Rotational Viscometer (RV) (AASHTO T 316 / ASTM D4402) for determining handling and pumping viscosity.
        - Dynamic Shear Rheometer (DSR) (AASHTO T 315 / ASTM D7175) to measure rutting and fatigue properties at intermediate to high temperatures.
        - Rolling Thin Film Oven (RTFO) Test (AASHTO T 240 / ASTM D2872) to simulate short-term aging.
        - Pressure Aging Vessel (PAV) (AASHTO R 28 / ASTM D6521) to simulate long-term in-service aging.
        - Bending Beam Rheometer (BBR) (AASHTO T 313 / ASTM D6648) to measure low-temperature stiffness and creep properties related to thermal cracking.
        - Direct Tension Test (DTT) (AASHTO T 314) to evaluate low-temperature tensile strength and strain properties.[18]

2.3 Regional Considerations and Market Preferences

The adoption and preference for specific asphalt standards and grading systems vary geographically.

- **Middle East & Africa:** Penetration-graded bitumen, such as grade 60/70, remains common for standard road construction and roofing applications.[10] However, there is a discernible shift towards Performance-Graded (PG) specifications to better address the region's diverse and often extreme climatic conditions. This includes the development of pavement temperature maps to aid in the selection of appropriate PG binders.[19] Prominent bitumen producers in the Middle East, including Saudi Aramco, Jey Oil Refining Company (Iran), Bahrain Petroleum Company (Bapco), Emirates National Oil Company (ENOC), and Kuwait Petroleum Corporation (KPC), supply a wide array of bitumen grades, including standard penetration grades and polymer-modified bitumens (PMB), to meet both domestic and international demands.[10]
- **Europe:** European Norms (EN) are the prevailing standards. The EN 13108 family of standards covers asphalt products such as Asphalt Concrete (AC), Hot Rolled Asphalt (HRA), and Stone Mastic Asphalt (SMA), while the EN 12697 family details the associated testing procedures.[13] In the United Kingdom, for instance, the Published Document PD 6691 provides national guidance on the application of EN 13108 standards, particularly for AC, HRA, and SMA mixtures.[13]

The diversity in global asphalt standards and grading systems underscores the necessity for a refiner aiming to sell SDA pitch-derived asphalt internationally to conduct thorough market research. Identifying target regions and their specific standard requirements (ASTM, AASHTO, or EN) and grading systems (Penetration, Viscosity, or Performance-Graded) is a prerequisite. This will likely necessitate flexible production capabilities to formulate products meeting varied specifications, or a strategy focused on specific product lines tailored to particular markets. The increasing global emphasis on pavement performance and durability, reflected in the adoption of PG specifications, suggests that producing a PG-compliant binder from SDA pitch, although requiring more sophisticated testing and potentially complex modification, could offer access to premium markets and a competitive edge, particularly for applications in demanding climates or under heavy traffic conditions.

Table 2.1: Key International Asphalt Standards and their Primary Focus

Standard Designation	Issuing Body	Asphalt Type Covered	Key Parameters Specified	Primary Region(s) of Use
ASTM D946	ASTM	Penetration-Gra	Penetration,	North America,

	International	ded	flash point, ductility, solubility, thin-film oven test results	Widely Referenced Globally
ASTM D3381/D3381M	ASTM International	Viscosity-Graded	Viscosity at 60°C & 135°C, penetration, flash point, solubility, ductility (on TFOT residue)	North America, Other Regions
ASTM D6373	ASTM International	Performance-Graded (PG)	High and low temperature performance grades, DSR, BBR, DTT, PAV, RTFO parameters	North America, Increasingly Global
AASHTO M 320	AASHTO	Performance-Graded (PG)	High and low temperature performance grades, DSR, BBR, DTT, PAV, RTFO parameters	USA
EN 12591	CEN	Paving Grade Bitumens (Pen)	Penetration grades (e.g., 35/50, 50/70), softening point, Fraass breaking point, kinematic viscosity, resistance to hardening	Europe
EN 13108 Series	CEN	Asphalt Concrete Products	Specifications for Asphalt Concrete, Hot Rolled Asphalt, Stone Mastic	Europe

			Asphalt, etc. (mixture properties)	
EN 12697 Series	CEN	Asphalt Test Methods	Test methods for hot mix asphalt	Europe

This table serves as a foundational guide to the complex landscape of asphalt standards. For the refinery considering the sale of SDA pitch as asphalt, it highlights the critical need to align product development and quality assurance with the specific requirements of the intended markets.

3.0 SDA Pitch as an Asphalt Feedstock

The viability of utilizing UOP SDA pitch as a component in asphalt production hinges on understanding its inherent properties, how these compare to standard asphalt specifications, and the modifications necessary to create a marketable product. Global practices indicate that while direct use is uncommon, SDA pitch can be valorized through blending or further processing.

3.1 Typical Properties of UOP SDA Pitch

SDA pitch is the heaviest product stream from the Solvent Deasphalting unit, concentrating asphaltenes, Conradson Carbon Residue (CCR), metals, and other contaminants originally present in the vacuum residue feed.[1] UOP's Demex process, a notable SDA technology, employs supercritical solvent recovery, as does the joint Wood Foster Wheeler/UOP SDA process, which can utilize solvents ranging from C3 to C7 paraffins.[1]

The physical and chemical characteristics of SDA pitch distinguish it significantly from conventional asphalt binders. A study evaluating two SDA pitches from different South Korean refineries revealed the following [2]:

- **Penetration (at 25°C, 100g, 5s, dmm):** Extremely low values of 6 and 29 were recorded, compared to 82 for a conventional AP-5 asphalt binder. This indicates a very hard material.
- **Softening Point (Ring & Ball, °C):** Significantly higher than conventional asphalt, with values of 61°C and 71°C versus 47°C for AP-5.
- **Ductility (at 15°C, 5 cm/min, cm):** Exceptionally low, measured at 0.2 cm (2 mm) for both pitches, compared to over 140 cm (1400 mm) for AP-5, signifying

extreme brittleness.

- **Viscosity (Rotational, Pa·s):** Markedly high. At 135°C, the pitches exhibited viscosities of 1075 Pa·s and 2125 Pa·s, substantially higher than the 435 Pa·s of AP-5. Measurements at 100°C were often not possible due to the high viscosity.
- **Asphaltene Content:** SDA pitch inherently contains a higher concentration of asphaltenes compared to conventional asphalt binders.[2] SARA (Saturates, Aromatics, Resins, Asphaltenes) analysis of the studied pitches showed aromatics constituting over 50%, with resins and asphaltenes each around 20%, and saturates at a low 1-3%.[2] The lower saturate content may contribute to its brittleness.[2]

Overall, neat SDA pitch is generally characterized as too hard and brittle for direct application as road paving asphalt, primarily due to its very high viscosity and extremely low ductility.[1]

3.2 Comparison with Paving Asphalt Specifications

When compared directly to standard paving asphalt specifications, unmodified SDA pitch typically falls short on several critical parameters. Its low penetration and ductility, coupled with high softening point and viscosity, mean it would not meet the requirements for common paving grades without significant modification.[2] While its high stiffness might theoretically offer good resistance to permanent deformation (rutting) at high temperatures, this is offset by a very high propensity for cracking, especially at low to intermediate temperatures, due to its brittleness.[2]

Table 3.1: Comparison of Typical UOP SDA Pitch Properties vs. Standard Paving Asphalt (e.g., 60/70 Pen Grade)

Property	Typical SDA Pitch Range	Typical 60/70 Asphalt Specification	Significance of Difference for Paving Applications
Penetration @ 25°C (dmm)	6 - 29	60 - 70 (for 60/70 grade); 50-70 (for 50/70 grade [11])	Pitch is excessively hard, lacks flexibility.
Softening Point (°C)	61 - 71	49 - 56 (for 60/70 grade [10]); 46-54 (for 50/70 grade [11])	Pitch is too stiff at typical service temperatures, potentially brittle.

Ductility @ 15°C or 25°C (cm)	0.2 (@ 15°C)	>100 (often specified for 25°C)	Pitch is extremely brittle, indicating poor cohesion and cracking resistance.
Rotational Viscosity @ 135°C (Pa·s)	1075 - 2125	Approx. 0.3 - 0.6 (typical for paving grades, AP-5 was 0.435 Pa·s [2])	Pitch is far too viscous for proper mixing and compaction.
Asphaltene Content (wt%)	~20 (can be higher)	10 - 20 (varies)	Higher asphaltenes contribute to hardness; balance with maltenes is crucial.
Saturate Content (wt%)	1 - 3	5 - 15 (varies)	Low saturates can contribute to brittleness and poor low-temperature performance.

This comparison clearly illustrates that SDA pitch requires substantial modification to meet the balanced properties required for durable and workable paving asphalt.

3.3 Global Practices: Selling SDA Pitch for Asphalt Applications

The direct sale of SDA pitch as a finished road asphalt product is not a common global practice due to its unsuitable native properties.[1] However, technologies and strategies exist to incorporate SDA pitch into asphalt products:

- **Blending/Modification:** This is the predominant approach.
    - Licensors of SDA technology, such as Lummus Technology, KBR (ROSE process), and Wood Foster Wheeler/UOP, acknowledge that pitch can be blended into asphalts or used to produce asphalt blending components.[3] For instance, KBR's ROSE asphaltene product from Holly Corp. Artesia was noted for "FCC Feed Asphalt," which implies use as an intermediate feedstock within the refinery rather than a final asphalt product for external sale.[22] The Wood Foster Wheeler/UOP SDA process description explicitly states that pitch "can be used in specification asphalts".[21]
    - Axens' Solvahl™ SDA technology also mentions that the produced pitch can be "valorized as bitumen" [24], though specific processing details are proprietary.

    - Pörner's "SDA PLUS" technology indicates that the high-asphalt pitch can be processed into bitumen using their Biturox® process or by blending, depending on the residue source and desired bitumen quality.[4] The Biturox® process is a mild air oxidation technology that takes selected feedstock blends (which can include SDA pitch or Propane Deasphalted Asphalt-Pitch, PDA-P) and, through controlled reaction in a specialized loop reactor, produces various bitumen grades, including multigrade bitumens with tailored properties.[25] This suggests a more involved chemical conversion rather than simple physical blending.
- **Alternative Dispositions:** If not valorized into asphalt, SDA pitch is typically utilized as feedstock for conversion units like delayed cokers, fluid/flexi cokers, or gasifiers (for hydrogen or syngas production), or it can be blended into heavy fuel oil pools.[1] Solidification of pitch for use as solid fuel is another option.[28]

The presence of multiple SDA technology licensors acknowledging asphalt blending as a potential disposition for pitch, coupled with specialized bitumen production processes like Biturox® that can utilize pitch, indicates that pathways exist for its use in asphalt. However, it is rarely a direct "as-is" application.

3.4 Blending SDA Pitch for Asphalt Production

Given that neat SDA pitch is too hard and brittle, modification through blending is essential to produce paving-grade asphalt.

3.4.1 Need for Modification

The primary objective of blending SDA pitch is to soften it, improve its ductility, and adjust its rheological properties to meet the specific requirements of paving asphalt standards.[2] This generally involves reducing its viscosity and softening point while increasing its penetration value and flexibility, particularly at low service temperatures. This is achieved by incorporating softer bituminous components or specialized flux oils and cutter stocks.[16]

3.4.2 Flux Oils and Cutter Stocks: Types and Properties

Flux oils are less volatile petroleum fractions used to permanently soften hard bitumen or pitch, while cutter stocks are more volatile solvents (like kerosene or naphtha) used to temporarily reduce viscosity for applications like cutback asphalts, where the solvent evaporates after application.[32] For producing paving grade asphalt from SDA pitch, flux oils are more relevant.

Common petroleum-derived flux oils suitable for blending with hard pitch include:

- **Vacuum Gas Oil (VGO):** A refinery distillate stream boiling between atmospheric gas oil and vacuum residue.[36] Typical VGO [37] has a viscosity around 130 SUS at 100°F (approx. 27 cSt @ 40°C) and low metals content. While DAO from SDA units can be a feedstock for VGO conversion units [1], VGO itself can also serve as a flux.
- **Light Cycle Oil (LCO):** A distillate product from Fluid Catalytic Cracking Units (FCCUs), typically in the diesel boiling range. LCO is characterized by its high aromatic content (50-80 wt%) and relatively low viscosity.[36] Its properties (density 0.82-0.88 kg/L, Flash Point >63°C [38]) make it a potential cutter or soft flux component. Some refineries add LCO to slurry material as cutter stock.[39]
- **Heavy Cycle Oil (HCO):** Also an FCCU product, HCO is heavier and more aromatic than LCO.[36] Its higher aromaticity could offer good compatibility with the asphaltenic pitch.
- **Decanted Oil (DO) / Clarified Slurry Oil (CSO):** The heaviest FCCU byproduct, characterized by very high aromaticity, high density, and high Bureau of Mines Correlation Index (BMCI).[36] Typical properties for an extract derived from slurry oil include density ~1.08-1.12 g/ml and BMCI of 127-144.[42] Slurry oil itself is a dark, high viscosity liquid, often stored hot (~93°C), with a molecular weight range of 250-1000, and contains asphaltenes and polar aromatics.[44] Blending deoiled asphalt (DOA), which is similar to SDA pitch in its high asphaltene content, with FCC slurry oil (e.g., 40 wt% slurry) has been shown to produce paving asphalt meeting specifications.[43]
- **Aromatic Extracts:** These are byproducts from solvent extraction processes in lube oil refining, such as Distillate Aromatic Extract (DAE) or Furfural Extract. They are rich in aromatic compounds and can serve as effective fluxing agents.[47] DAEs are complex, highly viscous liquids with hydrocarbons typically in the C15 to C50 range.[53] Specifications for various DAE grades (DAE 10 to DAE 60) show kinematic viscosities at 100°C ranging from 10 to 60 cSt, specific gravities around 0.995-1.020, and aromatic carbon content (CA%) from 35% to 60%.[53]
- **"Asphalt Flux" / "Roofers Flux":** These are generic terms for heavy petroleum oils specifically marketed or used for softening hard bitumens or pitches to produce roofing asphalt or other grades.[37] Asphalt flux from used oil re-refining, for example, can have a viscosity at 100°C of around 100-200 cSt and an API gravity of 5-15.[37]
- **Vegetable Oil-Based Additives:** Research has shown that certain vegetable oil derivatives, such as rapeseed or linseed oil methyl esters, can effectively modify SDA pitch, yielding properties comparable to conventional asphalt binders.[2] These offer a bio-based alternative to petroleum fluxes.

The choice of flux oil will depend on availability, cost, compatibility with the SDA pitch, and the desired properties of the final asphalt blend. Highly aromatic flux oils are generally preferred for compatibility with asphaltene-rich pitch.

Characterization Factors for Flux Oils:
To better understand the nature of flux oils and predict their blending behavior, characterization factors are often used:

- **Watson K Factor (UOP K Factor):** Calculated as (TB)1/3/SG, where TB is the mean average boiling point in degrees Rankine and SG is the specific gravity at 60°F. It indicates the general chemical nature: Paraffinic (K = 11-12.9), Naphthenic (K = 10-11), Aromatic (K < 10).[56]
- **Bureau of Mines Correlation Index (BMCI):** Calculated from mean average boiling point and specific gravity. For n-paraffins, CI = 0; for cyclohexane, CI = 50; for benzene, CI = 100. Crude oil fractions are classified as Paraffinic (CI < 29.8), Naphthenic (CI < 57.0), or Aromatic (CI > 75.0).[56] Flux oils with higher aromaticity (lower K factor, higher BMCI) are generally better solvents for asphaltenes.

Table 3.2: Overview of Potential Flux Oils/Cutter Stocks for SDA Pitch Blending

Flux Oil Type	Typical Source	Approx. Viscosity @100°C (cSt)	Approx. Density (kg/m³)	Approx. Aromatic Content (wt%)	Approx. Boiling Range (°C)	BMCI / Watson K (Indicative)	Potential Advantages	Potential Disadvantages/Compatibility Concerns with Hard Pitch
Vacuum Gas Oil (VGO)	Refinery Vacuum Distillation	~5-15 (highly variable)	~900-950	Moderate	~350-550	K ~11-12 (Naphthenic/Paraffinic)	Available in refinery	Lower solvency for high asphaltene pitch compared to aromatic fluxes.

Light Cycle Oil (LCO)	FCC Unit	~2-4	~820-880	50-80	~200-380	K <10 (Aromatic)	Good solvency, readily available	May be too light for significant softening; potential volatility issues if not fully incorporated.
Heavy Cycle Oil (HCO)	FCC Unit	~5-20	~950-1050	High	~350-500+	K <10 (Aromatic)	Higher aromaticity than LCO, better solvency	Availability may be limited.
Decanted Oil (CSO)	FCC Unit Bottoms	~10-50 (variable, can be higher)	~1050-1120	Very High (>80)	>350 (wide range)	BMCI >100 (Highly Aromatic)	Excellent solvency for asphaltenes	High density, may contain catalyst fines if not well clarified, can be highly viscous itself.
Aromatic Extract	Lube Oil Refinin	10-60+	~990-1020	35-60+ (as CA%)	Wide, typically >300	K <10 (Aromatic)	Specifically design	Cost and availab

(e.g., DAE)	g						ed for solvency, good compatibility	ility may be concerns; some DAEs have health/environmental restrictions.
Asphalt Flux / Roofers Flux	Various (e.g., re-refining)	50-200+	~950-1050	Variable	>350	Variable	Tailored for bitumen modification	Properties can vary widely depending on source.
Vegetable Oil Methyl Esters	Transesterification of Veg. Oils	~4-6 (@40°C)	~880	N/A (Oxygenated)	~300-370	N/A	Renewable, can impart good low-temp properties	Different chemistry, long-term stability and compatibility need thorough evaluation.

Note: Properties are indicative and can vary significantly based on crude source and processing conditions. Compatibility with SDA pitch must always be verified experimentally.

3.4.3 Assessing Pitch-Flux Compatibility

Blending dissimilar hydrocarbon streams, especially a highly asphaltenic pitch with a lighter flux oil, carries the risk of asphaltene precipitation if the blend is incompatible. This can lead to sludge formation in tanks, equipment fouling, and an off-specification, unstable asphalt product.[61] Lighter aliphatic diluents (e.g., C7 and lighter paraffins) are particularly known to destabilize asphaltenes.[61] Therefore, rigorous compatibility testing is crucial.

- **ASTM D4740 Spot Test:** This standard test method is used to determine the cleanliness of residual fuel oils and the compatibility of a residual fuel with a blend stock.[62] A drop of the heated sample (or a 50/50 blend of pitch and flux oil) is placed on a chromatographic paper and heated in an oven. The resulting spot is then compared to reference spots. A spot rating of Number 3 or higher indicates excessive suspended solids (for cleanliness) or incompatibility (for blends), suggesting a likelihood of operational problems like sludge formation or strainer plugging.[62]
- **P-value (Peptization State of Asphaltenes) and Related Parameters (ASTM D7112):** More sophisticated methods involve determining parameters that quantify the stability of asphaltenes in an oil matrix and the compatibility of different oils. The PORLA (Polarity and Asphaltene Research Laboratory Analyzer) or similar instruments are used for this purpose, often following ASTM D7112.[64] Key parameters include:
  - **P0 (Peptizing Power of Oil Medium):** The ability of the maltenes to keep asphaltenes dispersed.
  - **Pa (Peptizability of Asphaltenes):** The ease with which asphaltenes can be peptized or dispersed.
  - **FRmax (Flocculation Ratio Maximum):** The maximum ratio of aromatic solvent to paraffinic solvent at which asphaltene flocculation begins at infinite dilution.
  - **Xmin (Minimum Dilution):** The minimum amount of paraffinic solvent needed to cause flocculation in the undiluted oil.
  - **P-value:** An overall stability index. A P-value less than 1 typically indicates an unstable oil prone to asphaltene precipitation. For stable blends, P-values are generally greater than 1.2 or 1.5 depending on the application.[64]
- **Solubility Blending Number (SBN) and Insolubility Number (IN):** These parameters, also often determined using automated titration methods, provide another framework for assessing compatibility.[64]
  - **IN (Insolubility Number):** Represents the tendency of asphaltenes in a component to precipitate. Higher IN means greater precipitation risk.
  - **SBN (Solubility Blending Number):** Represents the power of a component

(or blend) to keep asphaltenes in solution. Higher SBN means better solvency.
    - **Compatibility Criterion:** A blend is generally considered compatible if the volumetric average SBN of the blend (SBNmix) is greater than the highest IN of any component in the blend (INmax).[64]
- **Hildebrand and Hansen Solubility Parameters:** These thermodynamic parameters can be used to predict the miscibility of components. The principle is that substances with similar solubility parameters are likely to be miscible.[66]
    - **Hildebrand Solubility Parameter (δ):** A single parameter representing the cohesive energy density of a substance: $\delta = (CED)^{1/2} = (\Delta E_v / V_m)^{1/2}$, where ΔE_v is the energy of vaporization and V_m is the molar volume.[66]
    - **Hansen Solubility Parameters (HSP):** Decomposes the Hildebrand parameter into three components: δ_d (dispersion forces), δ_p (polar forces), and δ_h (hydrogen bonding forces), where $\delta_{total}^2 = \delta_d^2 + \delta_p^2 + \delta_h^2$.[66,67,68]Forasphaltenesandalkanes(majorcomponentsofcrudeoilandfluxoils), thedispersionparameter(δ_d) is often dominant.[68]
    - Application: By determining the HSP values for the SDA pitch (particularly its asphaltene fraction) and various flux oils, one can assess their compatibility. Blends are more likely to be stable if the "distance" between their HSP values in the 3D Hansen space is small. This approach has been used to study the stability of residua and coking onset.[69]

Given the high asphaltene content of SDA pitch, relying solely on simple spot tests might be insufficient. A combination of ASTM D4740 with more quantitative methods like P-value determination or SBN/IN analysis is advisable for robust blend development and quality control.

Table 3.3: Compatibility and Stability Assessment Methods for Pitch-Flux Blends

Test Method	Principle	Key Output/Indication	Relevance to SDA Pitch Blending
ASTM D4740 Spot Test	Visual assessment of a spot made by a fuel/blend on filter paper after heating.	Spot rating (1-5); Rating ≥3 indicates excessive solids or incompatibility.	Quick, qualitative screening for gross incompatibility or instability of pitch-flux blends.[62]

P-value (e.g., ASTM D7112, PORLA)	Automated titration to determine the flocculation point of asphaltenes with paraffinic/aromatic solvents.	P-value, FRmax, Xmin, Pa, Po. P-value <1 indicates instability.	Quantitative assessment of asphaltene stability in pitch and its blends; helps optimize flux selection and ratios.[64]
Insolubility Number (IN) & Solubility Blending Number (SBN)	Titration-based determination of asphaltene precipitation tendency and solvent power.	IN and SBN values for components and blends. Compatibility if SBNmix>INmax.	Provides a quantitative criterion for blend compatibility, useful for formulating stable pitch-flux mixtures.[64]
Hansen Solubility Parameters (HSP)	Calculation or experimental determination of dispersion, polar, and hydrogen bonding solubility parameters.	δd,δp,δh values. Similar HSPs indicate better compatibility. "Solubility sphere" for pitch components.	Theoretical tool to predict miscibility and guide flux selection based on chemical affinity with pitch asphaltenes.[66] Can be complex to apply.

3.4.4 Methodologies for Determining Blend Ratios

Once compatible flux oils are identified, the next step is to determine the appropriate blend ratios to achieve the target asphalt specifications, primarily penetration and viscosity.

- **Target-Driven Formulation:** The blending process is guided by the need to meet specific paving grades, such as 60/70 or 80/100 penetration grade, or specific viscosity or PG grades.[31]
- **Blending Charts and Nomographs:**
  - Historically, graphical methods have been used. For penetration, a common logarithmic blending rule is: $\log P_{blend} = (w_A \log P_A + w_B \log P_B)$, where P is penetration and w is weight fraction. Similar nomographs exist for softening point.[70] An example from Alberta Transportation shows plotting RAP and virgin binder penetration/viscosity to determine recycle ratios for a target grade.[72]
  - Viscosity blending charts (e.g., ASTM D341 charts, which use a double logarithmic scale for kinematic viscosity versus temperature) can be adapted for blending calculations at a fixed temperature.

    - The Penetration Index (PI) can be used to characterize the temperature susceptibility of bitumen and its blends. Nomographs exist to determine PI from penetration and softening point values.[73] While not directly a blending ratio tool, ensuring the blend has an acceptable PI is important.
- **Viscosity Blending Equations:** Several empirical and semi-empirical equations are used to predict the viscosity of blends:
    - **Refutas Equation (Viscosity Blending Index - VBI):** This method calculates a VBI for each component based on its kinematic viscosity ($VBI_i = 14.534 \ln(\ln(v_i + 0.8)) + 10.975$). The VBI of the mixture is the weighted average of component VBIs ($VBI_{mixture} = \Sigma(x_i VBI_i)$). The mixture viscosity is then back-calculated from $VBI_{mixture}$.[70] This method is designed for a wide range of petroleum products.
    - **Kendall and Monroe Equation (Cubic Root):** Another empirical equation mentioned for viscosity blending.[74] The form is $\mu_{mix}^{1/3} = \sum x_i \mu_i^{1/3}$, where μ is viscosity and x_i is volume or mole fraction.
    - **Arrhenius-type Mixing Rule (for dynamic viscosity, η):** $\ln \eta_{mix} = \sum x_i \ln \eta_i$, where x_i is the mole fraction of component i.[74] This is theoretically based for ideal mixtures.
- **Conversion between Penetration and Viscosity:** Procedures like Tex-535-C allow for the calculation of viscosity from penetration test results at a given temperature.[75] This can be useful if the target is a viscosity grade, but initial blending trials are based on achieving a certain penetration. The relationship is empirical and depends on the needle geometry and penetration depth.
- **Laboratory Blending Trials:** Due to the complex nature of SDA pitch and flux oils, and the limitations of theoretical models, laboratory blending trials are indispensable.[31] These trials involve preparing blends at various ratios [2] and testing their properties (penetration, softening point, viscosity, ductility, DSR, BBR, etc.) against target specifications.

The inherent hardness and high asphaltene content of SDA pitch make it a challenging, yet potentially valuable, component for asphalt production. Its successful utilization requires careful selection of compatible and cost-effective fluxing agents. The high asphaltene concentration, if properly managed through blending, could contribute positively to properties like stiffness and rutting resistance, which are desirable in many paving applications. However, this must be balanced against the need to improve flexibility and low-temperature performance. The paramount importance of blend compatibility cannot be overstated. Asphaltene precipitation due to incompatible blending would lead to severe operational issues and an unusable final product. Therefore, a robust testing regime incorporating advanced compatibility assessment methods like P-value analysis or SBN/IN calculations, beyond basic spot tests, is highly recommended for developing stable and reliable SDA pitch-based asphalt formulations. Furthermore, exploring more advanced modification techniques, such as the Biturox® process involving mild oxidation [4], could offer a pathway to producing higher-value, specification-compliant bitumen grades from SDA pitch, potentially including multigrade bitumens, which might command a premium over simply fluxed products.

3.5 Valorization Strategy: Direct Sale vs. Blending of SDA Pitch

The primary consideration for valorizing SDA pitch is whether it can be sold "as is" or if it requires modification through blending to become a marketable asphalt product.

- **Direct Sale of Unmodified SDA Pitch:** As established in Sections 3.1 and 3.2, neat UOP SDA pitch typically exhibits properties such as extreme hardness, low penetration, high softening point, and very low ductility, making it generally unsuitable for direct use as a paving-grade asphalt.[1] Its inherent brittleness and high viscosity would likely lead to poor pavement performance, particularly in terms of cracking resistance, and difficulties in handling and application.[2] Therefore, selling SDA pitch directly as a finished asphalt product without any modification is not a common or viable industry practice.
- **Blending SDA Pitch with Other Components:** This is the predominant and more feasible strategy for incorporating SDA pitch into asphalt products.[3] This approach involves physically blending the hard SDA pitch with softer bituminous components or flux oils to adjust its properties to meet specific asphalt standards.[30]
    - **Flux Oils:** As detailed in Section 3.4.2, various refinery streams like Vacuum Gas Oil (VGO), Light Cycle Oil (LCO), Heavy Cycle Oil (HCO), or specialized aromatic extracts can be used to soften the pitch, improve its workability, and enhance its performance characteristics.[36]
    - **Softer Bitumen Grades:** Another method is to blend the SDA pitch with existing softer penetration-grade bitumens to achieve an intermediate grade that meets specifications.[16]
    - **Cutter Stocks:** For applications like cutback asphalts (though less common for paving today), SDA pitch could be blended with volatile petroleum solvents (cutter stocks) like kerosene or naphtha to temporarily reduce its viscosity.[33] The solvent evaporates after application.

This blending strategy is a physical modification aimed at producing "specification asphalts" [21] and does not necessarily involve further chemical processing, aligning with the objective of selling pitch as a final product or mixing it with other final products. Technology licensors, including those for UOP SDA processes, acknowledge that pitch can be utilized in specification asphalts, which inherently implies modification through blending to meet those required specifications.[21]

In conclusion, while direct sale of SDA pitch as a standalone asphalt product is generally not feasible due to its inherent properties, blending it with suitable flux oils or other softer bituminous components is a recognized and applicable method to produce marketable asphalt products.

4.0 Design and Construction of Large-Capacity Heated Pitch Storage Tanks (>600 m^3)

The storage of large volumes of SDA pitch, particularly when maintained at elevated temperatures (150-200°C) to ensure fluidity, demands meticulous engineering design and construction practices. This section outlines the applicable codes, material selection criteria, heating and insulation strategies, foundation design principles, mixing system requirements, and essential safety features for such a facility.

4.1 Applicable Design Codes and Standards

A comprehensive suite of industry standards governs the design, construction, and safe operation of large, heated pitch storage tanks. Adherence to these codes is critical for ensuring structural integrity, operational reliability, and regulatory compliance.

- **API 650: Welded Tanks for Oil Storage:** This is the cornerstone standard for designing and constructing vertical, cylindrical, aboveground, welded steel storage tanks operating at atmospheric or low internal pressures (up to 2.5 psig or 17.2 kPa).[5] It covers material selection, design calculations for shell, bottom, and roof, fabrication, erection, welding, inspection, and testing.
- **API 650 Appendix M: Requirements for Tanks Operating at Elevated Temperatures:** This appendix is of paramount importance for hot pitch storage, as it provides specific design rules, material considerations, and allowable stress adjustments for tanks operating at temperatures exceeding 93°C (200°F).[5] The user's specified storage temperature of 150-200°C falls squarely within the purview of Appendix M.
- **API 650 Appendix B: Recommendations for Design and Construction of Foundations for Aboveground Oil Storage Tanks:** This appendix offers guidance on geotechnical investigations, soil bearing capacity assessment, and various foundation types suitable for API 650 tanks.[5]
- **API 620: Design and Construction of Large, Welded, Low-Pressure Storage

Tanks: This standard applies to tanks designed for internal pressures greater than 2.5 psig (17.2 kPa) up to 15 psig (103.4 kPa) and temperatures not exceeding 121°C (250°F) unless additional provisions are met.[77] While pitch storage is typically atmospheric, API 620 might be relevant if specific process conditions or blanketing systems result in pressures exceeding API 650 limits.
- **NFPA 30: Flammable and Combustible Liquids Code:** This National Fire Protection Association standard provides essential safeguards for the storage, handling, and use of flammable and combustible liquids. It influences tank spacing, dike requirements, fire protection systems, and venting.[95] Hot pitch can generate flammable vapors, making NFPA 30 compliance critical.
- **API RP 571: Damage Mechanisms Affecting Fixed Equipment in the Refining Industry:** This recommended practice provides detailed information on various corrosion and metallurgical damage mechanisms, including sulfidation, which is relevant for high-sulfur pitch service.[92]
- **API RP 575: Inspection Practices for Atmospheric and Low-Pressure Storage Tanks:** This document guides the in-service inspection of storage tanks.[92]
- **API Standard 2000: Venting Atmospheric and Low-Pressure Storage Tanks:** This standard is crucial for designing normal operational venting (due to liquid movement and thermal breathing) and emergency venting systems (e.g., for fire exposure).[97]
- **API Standard 2350: Overfill Protection for Storage Tanks in Petroleum Facilities:** This standard provides guidance on designing and implementing overfill prevention systems to enhance operational safety and prevent spills.[96] Its principles are applicable to heavy asphaltic products.
- **NACE International Standards (e.g., NACE SP0198):** These standards are vital for addressing corrosion concerns, particularly Corrosion Under Insulation (CUI), which is a significant risk for hot, insulated tanks.[106]
- **Local and Regional Standards:** It is imperative to identify and comply with any specific national or local regulations governing the storage of asphalt, pitch, or hazardous materials. For example, if the refinery is in Egypt, relevant Egyptian codes for industrial storage tanks would apply, often referencing international standards like API 650.[116]

Table 4.1: Key Design Standards for Large Heated Pitch Storage Tanks

Standard	Aspect Covered	Key Relevance to Hot Pitch Storage Tank
API 650	General design, materials,	Primary structural design

	fabrication, erection, inspection of welded oil tanks	basis for the tank shell, bottom, and fixed roof.
API 650 Appendix M	Tanks operating at elevated temperatures	Mandatory for design at 150-200°C; dictates material allowable stress reduction, design details.
API 650 Appendix B	Foundation design recommendations	Guidance on geotechnical investigation, soil bearing capacity, foundation types, and thermal effects.
API Standard 2000	Venting of atmospheric and low-pressure tanks	Design of normal (operational) and emergency (fire exposure) vents to prevent overpressure/vacuum. Critical for hot, potentially vaporous pitch.
API Standard 2350	Overfill protection	Design of systems to prevent tank overfills, crucial for safety and environmental protection.
NFPA 30	Flammable and Combustible Liquids Code	Requirements for tank spacing, diking, fire protection systems, and handling of potentially flammable vapors from hot pitch.
NACE SP0198 (formerly RP0198)	Control of Corrosion Under Insulation (CUI)	Guidelines for selecting coatings, insulation materials, and inspection practices to mitigate CUI, a high risk for hot, insulated pitch tanks.
API RP 571	Damage Mechanisms in Refining	Information on sulfidation and other corrosion mechanisms relevant to high-sulfur pitch at elevated temperatures.
Local/Regional Construction & Safety Codes	All aspects of construction, safety, and environmental	Must be identified and adhered to; may impose

	compliance	stricter requirements than international standards.

4.2 Material Selection for High-Temperature (150-200°C), High-Sulfur Pitch Service

The selection of appropriate materials of construction is critical for the long-term integrity of a tank storing hot, potentially corrosive SDA pitch.

- **API 650 Appendix M Guidance:** As pitch is stored at 150-200°C, API 650 Appendix M is the governing document for material selection and allowable stress calculations.[6] This appendix provides methodologies to adjust the allowable design stresses for carbon and stainless steels to account for the reduction in strength at elevated temperatures. For example, a yield strength reduction factor, k, is applied, which is typically less than 1.00 for carbon steels at these temperatures.[83] The exact allowable stress values must be sourced from the current edition of API 650 Appendix M tables for the specific steel grade and design temperature. As a general indication, API 650 allowable design stress is often based on the lesser of 2/5 of tensile strength or 2/3 of yield strength at ambient temperature, which is then derated for temperature.[80]
- **Common Carbon Steel Grades for API 650 Tanks:**
    - **ASTM A516 Grade 60 or Grade 70:** These are pressure vessel quality carbon-manganese steels, well-suited for moderate and lower-temperature service where good notch toughness is important.[5] Grade 70 offers higher tensile and yield strength compared to Grade 60 and is often preferred for applications requiring greater strength.[120] ASTM A516 Grade 60 is explicitly mentioned for use in API 650 and API 620 storage tanks.[119] Both grades are listed in API 650 tank design calculations with specified allowable stresses.[124] These are strong candidates for hot pitch service, provided their properties are adequately derated per Appendix M.
    - **ASTM A285 Grade C:** This is a specification for low and intermediate tensile strength carbon steel plates used in pressure vessels.[82] It is approved by API 650, often for thinner sections, and is considered a more ductile, lower-cost alternative to A516 grades.[82] Its suitability for 150-200°C service would depend on the allowable stresses provided in Appendix M.
    - **ASTM A36:** A common structural steel, widely available and used for tank shells and bottoms in moderate service conditions.[5] Design calculations in [124] show A36 being used. Its application at 150-200°C would require careful checking of Appendix M allowable stresses.

    - API 650, Section 4, mandates that steel plates be manufactured using killed (fully deoxidized) steel and fine-grain practice to ensure good weldability and toughness.[82]
- **Allowable Stresses at 150-200°C:** The precise allowable design stress (Sd) and hydrostatic test stress (St) for the selected carbon steel grade at the design temperature (up to 200°C) must be determined from the tables in API 650 Appendix M. These values will be lower than the ambient temperature allowable stresses. For preliminary estimation, one might refer to similar codes like ASME B31.1 [84] to 11.7 ksi at 700°F (371°C)), but API 650 Appendix M is the definitive source for tank design.
- **Corrosion Considerations for High-Sulfur Pitch:**
    - **Sulfidation Corrosion:** This is a high-temperature corrosion mechanism occurring when metals react with sulfur compounds in hydrocarbon streams. For hydrogen-free environments, the threshold temperature for significant sulfidation is generally considered to be around 260°C (500°F) according to API 571.[127] Since the pitch storage temperature (150-200°C) is below this threshold, aggressive sulfidation of the bulk tank shell might not be the primary concern, unless localized overheating occurs or if naphthenic acids are also present, which can lower the effective threshold for sulfidation.[127] However, any H2S present in the pitch vapors in the tank headspace could contribute to corrosion.[128] API RP 571, "Damage Mechanisms Affecting Fixed Equipment in the Refining Industry," provides detailed guidance on sulfidation and other relevant corrosion mechanisms.[92]
    - **NACE MR0175/ISO 15156:** This standard primarily addresses sulfide stress cracking (SSC) and hydrogen-induced cracking (HIC) in sour service (H2S-containing) environments. While bulk pitch may not be considered a "sour service" in the traditional upstream sense, the presence of H2S in vapors or localized acidic conditions could make some of its principles relevant, particularly regarding material chemistry (e.g., sulfur content in steel <0.025% for some applications to avoid HIC).[129]
    - **Corrosion Allowance (CA):** API 650 mandates the inclusion of a corrosion allowance in thickness calculations for tank components.[5] A typical CA ranges from 2 mm to 5 mm.[82] Some analyses suggest that API 650 design rules inherently provide some "extra thickness" which can act as a CA, potentially allowing for zero *added* CA in non-corrosive services.[131] However, for hot, high-sulfur pitch, which has a potential for corrosion (even if not aggressive sulfidation of the shell), a conservative approach is warranted. A CA of at least 3 mm [124] should be considered for all wetted surfaces, including the tank bottom and lower shell courses. The final CA should be based on a detailed

corrosion review, considering actual sulfur species, potential for H2S in vapor space, operating temperature variations, and expected service life. NACE SP0198 also provides guidance on mitigating CUI, which is a form of corrosion.[106]

Table 4.2: Recommended Carbon Steel Grades & Indicative Allowable Stresses for Hot Pitch Service (Reference API 650 App. M)

ASTM Grade	Min. Yield Strength (Ambient, MPa)	Min. Tensile Strength (Ambient, MPa)	Indicative Allowable Design Stress (Sd) at 150°C (MPa) *	Indicative Allowable Design Stress (Sd) at 200°C (MPa) *	Key Considerations for Hot Pitch Service
A516 Gr. 60	220 [120]	415-550 [120]	Consult API 650 App. M	Consult API 650 App. M	Good toughness, widely used for pressure vessels and API 650 tanks. Preferred for reliable performance.
A516 Gr. 70	260 [120]	485-620 [120]	Consult API 650 App. M	Consult API 650 App. M	Higher strength than Gr. 60, suitable for thicker shells or higher loads. Good toughness.
A285 Gr. C	205 [126]	380-515 [126]	Consult API 650 App. M	Consult API 650 App. M	Lower strength, more ductile. May be cost-effective for thinner sections if

					allowable stress at temperature is adequate.
A36	250 (typical) [82]	400-550 (typical) [82]	Consult API 650 App. M	Consult API 650 App. M	Common structural steel, check suitability for elevated temperature per App. M. Impact testing may be required.

**Actual allowable stress values must be obtained from the latest edition of API 650 Appendix M for the specific design temperature. Values shown are for illustrative purposes of where to find data and are not design values.*

The design of a hot pitch storage tank requires a careful, integrated approach. The elevated temperature significantly impacts material strength, necessitating strict adherence to API 650 Appendix M for calculating derated allowable stresses. While aggressive sulfidation might be less of a concern at 150-200°C compared to higher refinery process temperatures, the high sulfur content of pitch combined with high temperature still warrants careful material selection and an appropriate corrosion allowance to ensure long-term asset integrity.

4.3 Tank Heating Systems

Maintaining the SDA pitch at an elevated temperature (typically 150-200°C) is essential to ensure its fluidity for storage, blending, and transfer operations.[132] The selection of an appropriate heating system is a critical design decision, impacting efficiency, cost, and safety.

- **Types of Heating Systems:**
  - **Hot Oil (Thermal Fluid) Systems:** These are indirect, closed-loop systems that circulate a specialized thermal fluid (mineral or synthetic oil) heated by a separate fired heater or electric heater. The hot thermal fluid then transfers heat to the pitch via coils or jackets inside the storage tank.[133] This method allows for high process temperatures at relatively low operating pressures.[133] Thermal oil heating is commonly used for bitumen tanks.[134]
  - **Steam Heating Systems:** Steam, generated by a boiler, is passed through

heating coils or a jacket on the tank to transfer heat to the pitch.[136] The maximum achievable temperature is dependent on the steam pressure; for instance, 250 psi (approx. 17 barg) steam has a saturation temperature of about 208°C (406°F).[136]
  - **Electrical Heating Systems:** This involves using electric resistance heating elements directly immersed in the pitch or as part of electric heat tracing on the tank shell and piping.[136] Electrical heating offers precise temperature control.
- **Heating Coil Design Considerations (for Hot Oil or Steam):**
  - **Material Selection:** Carbon steel is a common material for heating coils in both steam and hot oil service.[142] However, for potentially corrosive high-sulfur pitch, or if the heating medium itself could be corrosive (e.g., poor quality steam), stainless steel grades (e.g., 304L, 316L) offer superior corrosion resistance and are often preferred for demanding applications or higher temperatures.[137] The choice must consider the specific nature of the pitch and the heating medium.
  - **Heat Transfer Surface Area Calculation:** The required surface area of the heating coils is determined by the heat load (sum of energy needed to heat the pitch from an initial temperature to the storage temperature, plus ongoing heat losses from the tank surfaces) and the heat transfer characteristics of the system. The fundamental equation is $Q=U \cdot A \cdot \Delta TLMTD$, where Q is the heat transfer rate, U is the overall heat transfer coefficient, A is the surface area, and $\Delta TLMTD$ is the Log Mean Temperature Difference between the heating medium and the pitch.[137] The U-value is influenced by fluid properties (viscosity, thermal conductivity of pitch and heating medium), flow velocities, degree of fouling on coil surfaces, and coil material.[137] Finned coils are often used to increase the effective heat transfer surface area and reduce the required length of pipe.[144]
  - **Fluid Velocity (within coils):** Proper velocity of the heating medium inside the coils is important for achieving good heat transfer coefficients and preventing issues like fouling (for hot oil) or excessive condensate buildup (for steam).[137]
  - **Coil Layout:** Coils are typically arranged horizontally on the tank floor or in vertical bundles to promote even heating and natural convection within the viscous pitch.[145] For steam coils, a continuous slope is essential to ensure proper condensate drainage.[137] Multiple coils connected in series or parallel may be used to achieve the required surface area and flow distribution.[145]
- **Comparative Analysis of Heating Systems:**

Table 4.3: Comparison of Heating Mediums for Large Pitch Storage Tanks

Feature	Hot Oil System	Steam System	Electrical System
Efficiency	Generally high, especially at high temperatures. Closed-loop minimizes losses.[133]	Can be efficient if well-maintained, but prone to losses from steam traps, condensate return, and blowdown.[136]	Very high conversion efficiency at the heater, but overall efficiency depends on power generation source.
Temperature Capability	Can achieve very high temperatures (e.g., >300°C) easily.[133]	Limited by steam pressure; high temperatures require very high pressures.[136] 150-200°C is achievable.	Can achieve very high temperatures; limited by element sheath material.
Pressure Requirements	Low operating pressure, typically near atmospheric for the thermal fluid loop.[133]	Pressure directly related to temperature; can be high for 150-200°C steam.[136]	No process pressure associated with heating elements.
CAPEX (Relative)	Potentially higher for thermal fluid heater and specialized fluid. System simpler with fewer components (heater, pump, expansion tank).[147]	Boiler system can be complex (boiler, water treatment, condensate system, traps).[147] May be lower if existing steam infrastructure is available.	Can be high for large heating duties due to cost of elements and power supply infrastructure.
OPEX (Relative)	Generally lower due to higher efficiency, no water treatment, less corrosion, and potential for unattended operation.[133] Thermal fluid replacement is a	Higher due to water treatment, boiler blowdown, steam trap maintenance, and potential corrosion issues.[146] Licensed boiler operator may be	Dependent on electricity cost, which can be high. Maintenance generally lower than steam.

	periodic cost.	required.[133]	
Safety Considerations	Lower pressure operation is inherently safer. Thermal fluid leaks are a fire hazard if above autoignition temperature; fluid degradation over time.[133]	High-pressure steam leaks are a severe burn hazard. Boiler safety regulations are stringent.	Electrical hazards; requires proper grounding and protection.
Maintenance	Lower; no corrosion from water, no steam traps. Regular checks on thermal fluid quality and system integrity.[146]	Higher; regular maintenance of boiler, steam traps, condensate system, water treatment.[146]	Lower for elements; control systems need checking.
Suitability for Pitch	Excellent; widely used for asphalt/bitumen. Provides precise temperature control and high temperatures at low pressure.[133]	Suitable; has been traditionally used. May be less efficient for very high viscosity/temperature needs.	Suitable, especially for precise control or where other utilities are unavailable. May be less economical for very large heat duties.

For large-scale, high-temperature pitch storage, hot oil systems are often favored due to their ability to provide high, stable temperatures at low operating pressures, leading to potentially lower OPEX and enhanced safety compared to high-pressure steam systems. Electrical heating can be considered for smaller duties or where very precise control is paramount, but its OPEX can be significant for large tanks.

4.4 Thermal Insulation

Effective thermal insulation is critical for heated pitch storage tanks to minimize energy consumption, maintain stable product temperatures, ensure personnel safety from hot surfaces, and control Corrosion Under Insulation (CUI).

- **Material Selection:** The choice of insulation material depends on the operating temperature, compressive strength requirements (especially for tank bottoms), moisture resistance, and CUI resistance.

- **Mineral Wool (Rockwool/Stonewool):** A common choice for industrial high-temperature applications, suitable for temperatures up to approximately 650°C (1200°F) or higher depending on the specific product.[113] It offers good thermal insulation, acoustic properties, and is non-combustible (Euroclass A1).[150] Mineral wool is available in various forms, including blankets, boards, and pre-formed pipe sections.
- **Calcium Silicate:** An inorganic, non-combustible insulation material known for its high compressive strength and suitability for very high temperatures, often up to 650°C (1200°F) or even 982°C (1800°F) for specialized grades.[153] Water-resistant types and those incorporating corrosion inhibitors (like XOX inhibitor) are available, making them a good option where mechanical abuse or CUI is a concern.[153]
- **Cellular Glass (e.g., Foamglas®):** This material is rigid, closed-cell, impermeable to moisture, non-combustible, and possesses high compressive strength.[113] These properties make it an excellent choice for insulating tank bottoms, as it resists moisture ingress (critical for CUI prevention) and can withstand the high loads from the tank and its contents.[156] It can also be used on tank shells.

- **Thermal Conductivity (k-value) at Operating Temperatures (150-200°C):** The k-value (W/m·K) is a measure of a material's ability to conduct heat; lower k-values indicate better insulation. It's crucial to use k-values corresponding to the mean insulation temperature (average of hot surface and cold surface temperatures).
  - **Mineral Wool:** The k-value of mineral wool increases with temperature.[157] At ambient temperatures (around 20°C), k-values are typically in the range of 0.030-0.046 W/m·K.[157] For a mean temperature of 100°C, a k-value of approximately 0.047 W/m·K is reported.[157] For a mean temperature around 175°C (relevant for a 200°C pitch temperature and ~50°C outer surface), linear interpolation or manufacturer-specific data is necessary. Based on trends [158], a k-value in the range of **0.055 - 0.070 W/m·K** would be a reasonable estimate for mineral wool at a mean temperature of 175°C, but this must be verified with manufacturer data for the specific product density. [160] provides k-values for mineral wool at 15°C (0.033 W/mK) and 45°C (0.038 W/mK), confirming the increasing trend.
  - **Calcium Silicate:** Product data sheets provide k-values at specific mean temperatures. For instance, [154] lists calcium silicate (CS6L1, density 170 kg/m³) with a k-value of **0.055 W/m·K at a mean temperature of 200°C**. Another grade (CS6L2, density 220 kg/m³) has a k-value of **0.062 W/m·K at 200°C**. PROMASIL®-1000 (density 245 kg/m³) has a k-value of **0.075 W/m·K at a**

mean temperature of 200°C.[155]

- **Economic Insulation Thickness Calculation:** The optimal insulation thickness is determined by balancing the annualized cost of the insulation (material and installation) against the value of the heat saved over the insulation's lifetime. This is known as the "economic thickness".[161]
    - **Methodology:** The calculation involves:
        1. Determining the cost of heat loss for various insulation thicknesses.
        2. Determining the annualized installed cost for those thicknesses.
        3. Summing these two costs to find the total annual cost.
        4. The thickness that results in the minimum total annual cost is the economic thickness.
    - **Key Inputs:** Cost of energy (fuel or electricity), annual operating hours, efficiency of the heating system, hot surface temperature (pitch temperature), ambient temperature, thermal conductivity (k-value) of the insulation material at the mean operating temperature, installed cost of insulation per unit thickness (including labor and jacketing), and the amortization period for the investment.[161]
    - **Heat Loss Calculations:** Standard heat transfer equations are used. For flat surfaces (tank roof/bottom if simplified as flat): $Q=U \cdot A \cdot (Thot-Tambient)$, where U is the overall heat transfer coefficient. For cylindrical surfaces (tank shell): $Q=(Thot-Tambient)/Rtotal$, where Rtotal includes resistances of the pitch film, tank wall, insulation layer(s), and outer air film.[161] ASTM C680 "Standard Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Systems by Use of Computer Programs" provides detailed algorithms and methodologies for these calculations.[166] Examples of such calculations can be found in.[163]
- **Corrosion Under Insulation (CUI) Prevention (NACE SP0198):** CUI is a severe threat to hot, insulated carbon steel tanks, especially in the temperature range of -4°C to 175°C, which encompasses the lower end of the pitch storage temperature.[108] Pitch tanks operating at 150-200°C are within or very near this critical CUI range.
    - **NACE SP0198 "Control of Corrosion under Thermal Insulation and Fireproofing Materials - A Systems Approach"** is the key industry standard for CUI mitigation.[106]
    - **Key CUI Prevention Strategies:**
        1. **Protective Coatings:** Application of a suitable corrosion-resistant coating to the steel surface beneath the insulation is the primary defense. Immersion-grade coatings are recommended due to the potential for trapped water.[109] NACE SP0198 provides guidance on coating selection

based on service temperature. For instance, inorganic zinc (IOZ) primers should be topcoated for service up to 175°C.[109]

2. **Insulation Material Selection:** Choose insulation materials that absorb minimal water and dry out quickly if wetted.[113] Materials with low leachable chloride content are preferred to prevent stress corrosion cracking if stainless steel components are present (less relevant for carbon steel pitch tanks, but good practice). Cellular glass is often favored for its impermeability.[108]
3. **Weatherproofing/Jacketing:** The outer jacketing (typically aluminum or stainless steel) must be properly designed and installed with sealed joints and overlaps to prevent water ingress. Drainage features at low points are important.[111]
4. **Inspection and Maintenance:** A risk-based inspection (RBI) program should be implemented to detect CUI. Inspection methods include visual inspection of jacketing, removal of inspection plugs or windows, infrared thermography to detect wet insulation, neutron backscatter, pulsed eddy current, and radiography.[108] Inspection frequency depends on factors like equipment age, insulation condition, operating environment, and temperature cycling.[110]

The selection of insulation and its thickness is a critical engineering decision that directly impacts operational costs and asset integrity. For hot pitch storage, a robust insulation system designed with CUI prevention in mind is essential.

Table 4.4: Properties of Common Insulation Materials for Hot Pitch Tanks (150-200°C Service)

Material	Max Service Temp. (°C)	Typical k-value @ 175°C mean (W/mK)*	Compressive Strength	Water Absorption/Permeability	CUI Resistance Considerations	Pros	Cons
Mineral Wool (Rockwool/ Stonewo	~650-750+ [149]	0.055 - 0.070 (density dependent)	Low to Medium	Can absorb water if jacketing fails; water-re	Good if kept dry; can trap moisture if	Good thermal performance, non-combustibl	Can sag if not properly supported; potential

ol)				pellent grades available	wetted.	e, cost-effective, good for irregular shapes.	for moisture retention if jacketing is breached.
Calcium Silicate	~650-980+ [153]	0.050 - 0.075 (density dependent)	High to Very High [153]	Low (water-resistant types available)	Good, especially with corrosion inhibitors.[153]	High strength, good thermal stability, non-combustible.	More rigid (can be brittle), potentially higher cost than mineral wool.
Cellular Glass (e.g., Foamglas®)	~450-485 [108]	~0.055 - 0.065	Very High	Impermeable (closed-cell)	Excellent, acts as a vapor barrier.	Impermeable to water, high compressive strength, non-combustible, dimensionally stable.	Higher cost, can be brittle, requires careful installation to avoid joint damage.

**k-values are indicative and highly dependent on specific product, density, and mean temperature. Always consult manufacturer data.*

4.5 Foundation Design

The foundation for a large-capacity, hot pitch storage tank must be designed to safely support the substantial weight of the tank and its contents, while also accommodating environmental loads (wind, seismic) and the unique challenges posed by elevated operating temperatures. API 650 Appendix B provides the primary recommendations for tank foundation design.[5]

- **Geotechnical Investigation Requirements (as per API 650 Appendix B.2.2):** A thorough understanding of subsurface conditions is paramount.
  - **Purpose:** To determine the soil stratigraphy, engineering properties of the soil layers, soil bearing capacity, and to predict potential settlement (both magnitude and differential) under the tank load.[89]
  - **Methods:** The investigation typically involves a combination of soil borings, in-situ testing such as Cone Penetration Tests (CPT) and Standard Penetration Tests (SPT), and laboratory testing of recovered soil samples.[88]
  - **Number and Spacing of Borings/CPTs:** API 650 Appendix B.2.2.1 [91] recommends a minimum number of investigation points based on tank diameter:
    - Tanks up to 12 m (40 ft) diameter: Minimum 5 points (typically one at the center and four on the approximate shell circumference).
    - Tanks >12 m (40 ft) and up to 40 m (130 ft) diameter: Minimum 9 points.
    - Tanks >40 m (130 ft) diameter: Minimum 13 points.
    - CPTs or borings on the tank circumference should be spaced at approximately 10 m (32 ft) intervals.[91] The specific number and layout should be determined by a qualified geotechnical engineer based on site variability and tank size.
  - **Depth of Investigation:** Borings/CPTs should extend to a depth where the stress increase from the tank load is negligible (typically <10% of the effective overburden stress) or until a competent bearing stratum is encountered.[89] This depth can be significant, often 1 to 2 times the tank diameter for large tanks on compressible soils. [172] suggests the depth should be equal to or greater than the depth of the basement active area (compressible soil thickness).
- **Soil Bearing Capacity Assessment:**
  - The allowable soil bearing capacity is determined by the geotechnical engineer based on the investigation results, considering both shear strength failure and settlement criteria.[87]
  - API 650 Appendix B.2.3 suggests typical factors of safety against ultimate bearing failure: 2.0 to 3.0 for normal operating conditions, and 1.5 to 2.25 for hydrostatic test conditions or operating conditions combined with maximum wind/seismic loads.[89] These factors may be adjusted based on the reliability of soil data and the consequences of failure.
- **Foundation Types:** The choice of foundation depends on soil conditions, tank load, and settlement tolerances.
  - **Compacted Granular Pad (Earth Foundation):** Suitable for sites with competent, relatively incompressible soils. Consists of a well-compacted layer of granular material (e.g., sand, gravel).[5] The pad is typically crowned (sloped

from center to edge) to promote drainage and accommodate some bottom settlement.[172]

  - **Concrete Ringwall Foundation:** The most common type for large diameter steel tanks. A reinforced concrete ring beam is constructed directly beneath the tank shell to distribute the shell load and provide a level, stable support.[5] The area inside the ringwall is typically filled with compacted granular material or a lean concrete slab to support the tank bottom.[175]
  - **Reinforced Concrete Slab Foundation:** A full concrete slab under the entire tank area. More costly than a ringwall with granular fill but may be used for smaller tanks or where soil conditions are poor near the surface but improve with depth, or if a very rigid foundation is required.[79]
  - **Pile Foundations:** Used when shallow soils have insufficient bearing capacity or excessive settlement potential. Piles (steel, concrete, or timber) transfer the tank loads to deeper, stronger soil strata or bedrock.[175] A reinforced concrete pile cap or slab is constructed over the piles to support the tank.
- **Thermal Effects on Soil and Concrete Foundation (Critical for Hot Pitch Tanks):** The sustained high temperature of the stored pitch (150-200°C) will lead to heat transfer into the foundation and the underlying soil. This is a critical design consideration that goes beyond standard API 650 Appendix B guidance for ambient temperature tanks.[6]
  - **Impact on Soil Properties:**
    - **Moisture Content & Desiccation:** Prolonged heating can cause significant drying (desiccation) of cohesive soils (clays, silts) beneath the tank. This can lead to soil shrinkage, cracking, an increase in effective stress, and potentially differential settlement.[177] The bearing capacity of some soils can also be altered by temperature changes.
    - **Settlement Characteristics:** Temperature-induced changes in soil volume and strength can lead to long-term settlement or heave, which may be uneven and detrimental to the tank structure and connected piping.
  - **Impact on Concrete Foundation:**
    - **Temperature Limits for Concrete:** Concrete properties (strength, durability) degrade when subjected to sustained high temperatures. API 650 considers temperatures above 93°C (200°F) as "elevated".[6] For molten salt tanks (a more extreme case), a maximum permissible concrete temperature of 90°C was cited as a design constraint.[177] The foundation design must ensure that the concrete temperature remains within acceptable limits.
    - **Thermal Stresses and Expansion:** Differential thermal expansion

between the hot tank bottom and the cooler concrete foundation, as well as thermal gradients within the concrete itself, can induce significant stresses, potentially leading to cracking, spalling, and loss of structural integrity.[177]

- **Design Considerations for Thermal Effects:**
    1. **Tank Bottom Insulation:** Installing a layer of high-compressive-strength, thermally efficient insulation (e.g., cellular glass, specialized calcium silicate boards) directly beneath the tank bottom is crucial. This reduces heat flow to the foundation and soil, protecting them from excessive temperatures.[156]
    2. **Ventilated Foundations:** For very hot services, an air gap or ventilation channels beneath the tank bottom insulation layer might be considered to promote cooling by natural or forced convection, although this adds complexity. [177] discusses ventilation ducts for a molten salt tank.
    3. **Heat-Resistant Concrete:** If concrete temperatures are still expected to be high, specialized heat-resistant concrete mixes may be necessary.
    4. **Foundation Material Selection:** The material directly under the tank bottom (e.g., sand, bitumen-sand) must be stable at operating temperatures and not contribute to corrosion. API 650 Appendix B.3.2 advises against bitumen-sand layers under steel tank bottoms if cathodic protection is used, as they can shield current.[89] Clean, washed sand with controlled resistivity is often recommended.[181]
    5. **Geotechnical Analysis:** The geotechnical engineer must explicitly consider the effects of long-term heating on soil behavior in settlement and stability analyses.
    6. **Structural Design of Foundation:** The structural design of the concrete foundation (ringwall or slab) must account for thermal gradients and potential thermal expansion stresses, in addition to the tank and product loads. Process Industry Practice (PIP) standard STE03020 provides some guidelines for elevated temperature tank foundations, but notes they are minimal.[6]

The foundation for a hot pitch tank is a critical element. Failure to adequately address the thermal loads and their impact on the soil and concrete can lead to premature foundation failure, tank instability, and operational disruptions. A specialized geotechnical and structural engineering assessment, incorporating thermal analysis, is indispensable.

Table 4.5: Geotechnical Investigation Guidelines Summary (per API 650 App. B)

Investigation Aspect	API 650 App. B Recommendation	Relevance to Large Hot Pitch Tank
Purpose of Investigation	Determine soil bearing capacity, estimate settlement, identify problematic soil conditions.	Essential for all large tanks; thermal effects on soil add complexity for hot pitch.
Minimum Number of Borings/CPTs	- Tanks ≤ 12m D: 5 - Tanks >12m to ≤40m D: 9 - Tanks >40m D: 13 (One center, rest on circumference)	For >600 m^3 (implies D > ~10-12m), minimum of 9-13+ points. Spacing ~10m on circumference.
Depth of Borings/CPTs	To depth where stress increase from tank <10% of effective overburden stress, or to competent stratum.	Significant depth required (potentially 1-2 times tank diameter) due to large load and influence zone, especially on compressible soils. Must assess deep thermal effects.
In-Situ Testing	SPT, CPT recommended.	Standard practice; CPT provides continuous data valuable for heterogeneous soils.
Laboratory Testing	Classification, strength (e.g., shear strength), compressibility (e.g., consolidation) tests on representative samples.	Crucial for deriving design parameters. For hot tanks, tests on soil behavior under elevated temperatures may be warranted if not using under-bottom insulation.
Factors of Safety (Bearing Capacity)	Normal Operation: 2.0-3.0; Hydrotest: 1.5-2.25.	Standard FoS apply, but allowable bearing capacity might be reduced by thermal effects if not mitigated by insulation.
Special Considerations	Sites with variable soil, soft clays, organic soils, seismic activity, adjacent structures, potential for liquefaction.	All apply; additionally, long-term heat effects on soil properties are a special consideration for hot pitch

		tanks.

4.6 Tank Mixing Systems

Maintaining the homogeneity of blended SDA pitch, preventing sludge accumulation, and ensuring temperature uniformity throughout the large tank volume are critical operational requirements. This necessitates an effective tank mixing system.

- **Purpose of Mixing in Pitch Tanks:**
    - **Homogeneity:** Ensure uniform distribution of blended components (pitch and flux oil) and prevent stratification due to density or temperature differences.
    - **Sludge Prevention:** Keep asphaltenes and other heavy components in suspension, preventing their settling and formation of difficult-to-remove sludge at the tank bottom.
    - **Temperature Uniformity:** Distribute heat evenly from the heating coils, preventing localized overheating or cold spots which could lead to product degradation or solidification.
- **Types of Mixing Systems for Large Tanks:**
    - **Side-Entry Mechanical Mixers:** These mixers utilize propellers or specialized impellers mounted on the tank shell, typically below the liquid level.[141] They are effective for large volume blending, solids suspension (BS&W control in crude tanks), and maintaining homogeneity.[185]
    - **Jet Mixing Systems:** These systems use nozzles to introduce high-velocity jets of the stored liquid (recirculated by an external pump) into the tank, inducing mixing through entrainment and turbulence.[141] They have the advantage of no moving parts inside the tank. However, their effectiveness significantly diminishes with increasing fluid viscosity. Standard jet mixers are generally recommended for fluids with viscosities below 0.01 Pa·s (10 cP), and are stated to likely not provide satisfactory results for viscous fluids.[190] Given that hot pitch, even at 150-200°C, will have a viscosity significantly higher than this (likely in the range of 100s to 1000s of cP), conventional jet mixers may not be suitable unless specifically designed for high viscosity service or used in conjunction with other mixing methods.
- **Design Considerations for Mixing Viscous, Hot Pitch (Primarily for Side-Entry Mixers):**
    - **Impeller Selection:** For high viscosity fluids, specialized impeller designs are required. Standard marine propellers may not be efficient. Pitched blade turbines or high-efficiency hydrofoil impellers designed for viscous flow are more appropriate.[188] Some manufacturers offer heavy-duty side-entry mixers with true helical pitch, one-piece cast impellers incorporating high blade area

and forward rake for such applications.[184] For very viscous liquids (500-1000 cP and higher), the flow regime is likely to be laminar, requiring impellers that promote bulk movement rather than high shear, such as anchor or helical ribbon impellers, though these are typically top-entry.[189] The D/T (impeller diameter to tank diameter) ratio is typically larger for more viscous fluids, often in the range of 0.25 to 0.4 or even higher, to maximize flow.[186]

  - **Power Calculation:** Mixer power is a function of impeller geometry (Power Number, Np), rotational speed (N), impeller diameter (D), fluid density (ρ or SG), and fluid viscosity (μ).[186] The power equation is often expressed as P=Np·ρ·N3·D5·Kvisc, where Kvisc is a viscosity correction factor. For laminar flow (low Reynolds number, Re=ρND2/μ), Np is inversely proportional to Re, meaning power draw increases significantly with viscosity.[186] Accurate estimation of fluid properties at operating temperature is critical.
  - **Turnover Rate / Mixing Intensity:** The required degree of mixing or turnover rate (number of tank volume turnovers per hour) depends on the process objective (e.g., maintaining temperature uniformity, preventing sludge). For viscous liquids like pitch, achieving complete homogeneity and preventing settling may require significant energy input and specific turnover rates. Mild agitation for storage tank homogenization might aim for turnover times of 3-60 minutes [190], but this is for low viscosity fluids. For viscous pitch, longer turnover times or higher power per unit volume will be needed.
  - **Mixer Placement and Angling:** Side-entry mixers are typically installed near the tank bottom and angled slightly (e.g., 7-10 degrees) off the tank radius to induce a swirling flow pattern and avoid dead zones.[183] Multiple mixers are often required for large diameter tanks to ensure adequate coverage. CFD modeling can help optimize placement and angling.[190]
  - **Material of Construction:** Wetted parts, including shaft and impeller, should be made of materials resistant to corrosion by hot pitch (e.g., stainless steel 316SS is mentioned for chemical service [183]).
  - **Mechanical Seals:** Robust mechanical seals designed for high-temperature, viscous service are essential. Systems with oil purge or buffer fluids can protect the seal from direct contact with the hot, abrasive pitch and extend seal life.[183]
- **API Standards or Recommended Practices:** While API 650 covers tank construction, and standards like API 2000 cover venting, specific API standards or detailed recommended practices for the *design of mixing systems* within asphalt or pitch storage tanks were not explicitly found in the provided research. [128], an Asphalt Institute document on pyrophoric material formation, mentions mixing for polymer-modified asphalt but does not provide design guidelines. [141]

notes that ECF Inc. designs asphalt tanks with mixers to meet UL 142 or API 650, implying general compliance rather than specific mixing design codes within API 650. The design of such systems often relies on proprietary vendor expertise, general chemical engineering principles for mixing viscous fluids, and empirical data.

Given the high viscosity of SDA pitch even at elevated temperatures, side-entry mechanical mixers with robust designs (e.g., high-torque drives, specialized impellers for viscous media, and reliable high-temperature seals) are likely to be more effective than standard jet mixing systems for ensuring homogeneity and preventing sludge. Careful consideration of power requirements, number and placement of mixers, and impeller design will be crucial for achieving the desired mixing performance in a >600 m³ tank.

Table 4.6: Overview of Tank Mixing System Options for Viscous Pitch

Mixer Type	Suitability for High Viscosity Pitch	Homogenization Capability	Sludge Prevention	Temperature Uniformity	Key Design Parameters	Pros	Cons
Side-Entry Mechanical Mixer	Good, with appropriate impeller design (e.g., pitched blade, high-efficiency hydrofoil) and power [188]	Good to Excellent	Good, by maintaining particle suspension	Good, promotes bulk fluid movement	Impeller type & diameter, speed, power, D/T ratio, placement, seal design.	Effective for large volumes, proven technology for viscous fluids, good for BS&W control.[1] [85]	Moving parts inside tank require maintenance (seals, bearings), higher initial cost for robust units.
Jet Mixing System (Conven	Poor to Fair; generally not	Fair to Poor in highly viscous	Limited effectiveness in viscous	Fair, if sufficient flow can be	Nozzle design, jet velocity,	No moving parts inside	Low efficiency in viscous

tional)	recommended for high viscosity (>10 cP) without specialized design[190]	fluids	fluids; may not prevent settling	induced	recirculation rate, number & placement of nozzles.	tank, potentially lower maintenance on internal components.	liquids, high pumping power required, potential for localized shear without bulk movement.

4.7 Safety and Environmental Systems

Operating a large-capacity storage tank for hot, potentially hazardous SDA pitch necessitates comprehensive safety and environmental protection systems. Key standards guiding these systems include API 2350 for overfill protection, API 2000 for venting, and NFPA codes (e.g., NFPA 11, NFPA 30) for fire protection.

- **Overfill Protection (API Standard 2350):** Preventing tank overfills is paramount to avoid spills, environmental damage, and potential fire hazards. API 2350, "Overfill Protection for Storage Tanks in Petroleum Facilities," provides a framework for designing and managing overfill prevention systems (OPS).[96]
  - **Key Elements:** The standard emphasizes a management system approach, defining roles, responsibilities, documentation, and training. Operationally, it requires defining critical liquid levels within the tank:
    - **Critical High (CH) Level:** The highest level before product overflows, tank design stresses are exceeded, or internal components are damaged.
    - **Levels of Concern (LOCs):** Predetermined levels that trigger alarms or automated actions (e.g., pump shutdown, flow diversion). Common LOCs include High (alarm), High-High (alarm and/or shutdown), and Maximum Working Level (MWL).
  - **Applicability to Pitch:** API 2350's principles apply to heavy asphaltic products, which are often considered an environmental hazard if spilled.[96] For heated pitch, accurate level measurement technology tolerant of high temperatures and potential coating is essential.
- **Tank Venting (API Standard 2000):** Proper venting is required to prevent tank damage from overpressure or vacuum during normal operations and emergency conditions.[97]

- **Normal Venting:** Accommodates pressure changes due to:
    - **Liquid Movement:** Vapor displacement during filling (outbreathing) and air intake during emptying (inbreathing).
    - **Thermal Breathing:** Expansion and contraction of vapors in the tank headspace due to ambient temperature changes or changes in stored product temperature (outbreathing and inbreathing). For hot pitch, maintaining temperature will lead to continuous thermal considerations. The presence of insulation is a factor in calculating thermal breathing rates.[102]
- **Emergency Venting (Fire Exposure):** Sized to relieve pressure generated by the vaporization of the tank contents during an external fire. API 2000 provides methodologies for calculating the required venting capacity based on the tank's wetted surface area and an environmental factor 'F' which accounts for insulation.[103]
    - For Class III-B liquids like asphalt or pitch (which have high flash points, typically >93°C), NFPA 30 and IFC may have less stringent emergency venting requirements for very large tanks if they are not located in a common dike with Class I or II liquids, based on the premise that they are difficult to ignite and boil.[97] However, since the pitch is stored hot (150-200°C), its vapor pressure will be higher, and vapor generation under fire exposure needs careful evaluation according to API 2000.
- **Vent Piping Considerations:** For products with high freezing/solidification points like pitch, vent piping may require insulation and heat tracing to prevent plugging from condensed vapors or solidified product, especially in colder ambient conditions.[102]

- **Fire Protection Systems (e.g., NFPA 11, NFPA 30, API RP 2001):** Given the combustible nature of hot pitch and its vapors, robust fire protection is essential.
  - **NFPA 30:** Governs general requirements for flammable and combustible liquid storage, including tank spacing and diking.[95]
  - **NFPA 11: Standard for Low-, Medium-, and High-Expansion Foam:** This is the primary standard for designing foam fire suppression systems for petroleum storage tanks.[192]
    - **Foam Concentrate Selection:** For hydrocarbon fires (like asphalt/pitch), protein, fluoroprotein (FP), film-forming fluoroprotein (FFFP), or aqueous film-forming foam (AFFF) concentrates are typically used. For hot, viscous products, foams that can create a stable, heat-resistant blanket are preferred. The choice may depend on the specific type of foam delivery system. Alcohol-resistant AFFF (AR-AFFF) is for polar solvents/water-miscible liquids, which is not typical for pitch.[195]

- Foam Application Rates: NFPA 11 specifies minimum foam solution application rates based on the fuel type and tank configuration. For fixed-roof tanks storing hydrocarbons, a common minimum application rate is 4.1 L/min/m² (0.1 gpm/ft²) of liquid surface area.[196] This rate can be adjusted based on specific hazards and foam discharge device type.
- **Application Duration:** Minimum foam discharge duration is also specified, often depending on the fuel's flash point. For fuels with flash points above 38°C (which includes hot pitch), a typical duration might be 30-55 minutes.[196]
- **Foam Delivery Systems:** For fixed-roof tanks, foam is typically applied via Type II applicators (foam chambers discharging foam gently onto the liquid surface) or subsurface injection systems (though the latter is less common for very viscous products and modern foams may have limitations [196]).

- **API RP 2001: Fire Protection in Refineries:** Provides overall guidance on fire protection philosophies and systems in refinery settings.[197]
- **Tank Cooling Systems:** Fixed water spray systems (per API RP 2030 [197]) or firewater monitors are used to cool the tank shell and roof during a fire, preventing structural failure and reducing vaporization rates.[195]
- **Bund Wall / Dike Area Protection:** The area within the secondary containment (bund wall) must also be protected, typically with medium-expansion foam systems, to handle spills and leaks.[195]
- **Pyrophoric Iron Sulfide Hazard:** Hot asphalt storage tanks, especially those with H2S in the vapor space, can form pyrophoric iron sulfide deposits in the coke on tank internals. These can ignite spontaneously when exposed to air during tank cleaning or maintenance.[128] API RP 2023 [128] addresses this. Maintaining specific oxygen concentrations in the headspace is a debated mitigation strategy.[128]

Table 4.7: Key Safety and Environmental Systems for Hot Pitch Tanks

System	Relevant Standard(s)	Key Design Considerations for Hot Pitch Service
Overfill Protection	API 2350	Define Critical High Level and LOCs. Use high-temperature tolerant level sensors. Ensure reliable alarms and automated

		shutdown/diversion logic. [96]
Normal Venting	API 2000	Calculate thermal inbreathing/outbreathing for 150-200°C product and ambient variations. Size for maximum filling/emptying rates. Consider insulation and heat tracing for vent lines to prevent plugging. [102]
Emergency Venting (Fire Case)	API 2000, NFPA 30	Calculate required relief capacity based on wetted area, insulation factor (F), and properties of hot pitch. Ensure emergency vents (e.g., PVRVs, emergency manholes) are adequately sized and functional. [97]
Fire Suppression (Foam)	NFPA 11	Select appropriate foam concentrate (e.g., FP, FFFP) for hot hydrocarbon. Design foam delivery system (e.g., foam chambers) for specified application rate (e.g., ≥4.1 L/min/m2) and duration. [195]
Tank Cooling	API RP 2030	Fixed water spray systems or monitors to cool tank shell and roof during external fire exposure. [195]
Secondary Containment (Dike/Bund)	NFPA 30, Local Regulations	Sized to contain spills. Consider foam protection for dike area fires. [195]
Headspace Inerting (Optional)	N/A (Best Practice)	Consider nitrogen blanketing to reduce vapor space flammability and mitigate pyrophoric iron sulfide formation, though this has

		implications for venting design. [128]

4.8 Real-World Examples and Case Studies

Detailed, publicly available case studies specifically documenting the design, construction, and operational performance of very large (>600 m^3) heated storage tanks for UOP SDA pitch are scarce in the provided research materials.[128] Most available information pertains to general bitumen/asphalt storage or smaller specialized tanks. However, by examining specifications from tank suppliers and general industry practices for hot, viscous product storage, key design features can be inferred:

- **General Design Features from Bitumen Tank Suppliers (often smaller scale but indicative):**
  - **Materials of Construction:** Mild steel or carbon steel is commonly used for the tank shell and bottom.[116] Stainless steel might be used for internals or in highly corrosive environments.
  - **Heating Systems:** Thermal oil (hot oil) heating systems are prevalent for bitumen storage due to their ability to achieve high, stable temperatures at low pressures.[134] Heating coils are typically located at the tank bottom, arranged for optimal heat distribution.[134] Electric heating is also an option, particularly for smaller tanks or where precise temperature control is paramount.[134]
  - **Insulation:** Robust thermal insulation is standard, often 50 mm to 300 mm thick depending on design and efficiency targets.[135] Mineral wool (Rockwool) or fiberglass, clad with aluminum or galvanized steel sheeting, is common.[135] Tank roofs and sometimes bottoms are also insulated to minimize heat loss.[141]
  - **Mixing/Agitation:** To maintain homogeneity and prevent settlement, especially for modified bitumens or viscous products, tanks are often equipped with mixing systems. These can include side-entry propeller mixers or internal jet mixing systems.[134]
  - **Safety and Instrumentation:** Standard fittings include temperature gauges, level indicators (radar gauges are common [135]), pressure/vacuum relief valves, emergency vents, and often emergency shutdown systems.[134] Explosion-proof designs for electrical components are typical where flammable vapors may be present.[134]
- **Large Tank Construction Practices (API 650):**
  - Tank bottoms are typically assembled first, often with a central part and segmental outer rings.[199]

- Shells are constructed course by course

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