

Sirdaryo IES filialidagi sovutish tizimlarini optimalashtirish: yuqori harorat sharoitida muqobil usullar

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Dolzarbli: Maqola 2026-yilda juda dolzarb hisoblanadi, chunki u iqlim o'zgarishi, suv resurslarining yetishmovchiligi va infratuzilmani modernizatsiya qilish sharoitida O'zbekistonning dolmuş energetika muammolariga bag'ishlangan. Tadqiqot shuni ko'rsatadiki, gibrid "ho'l/quruq" sovutish tizimlari, yog 'sovutish uchun issiqlik quvurlari va sovutgichlar uchun bug 'lanish oldi sovutish takliflari optimal haroratdan har 10 ° C harorat ko'tarilishi uchun samaradorlik yo'qotishlarini 1-3% kamaytirishi mumkin, shu bilan birga suv tejankorligini 30-80% ta'minlaydi — bu yozda harorat 45 ° C dan oshadigan va 2030 yilga kelib suv tanqisligi yiliga 15 mlrd m³ ga yetishi kutilayotgan qurg'oqchil mintaqada juda muhimdir. Dalillar maqolaning o'z vaqtida ekanligini ko'rsatadi, Sirdaryo IES ning joriy modernizatsiyasini, jumladan, 2025-2026 yillarda ishga tushirilishi rejalashtirilgan 1573 MVt quvvatga ega yangi bug '-gaz energoblokini, Yevropa Qayta Qurish va Taraqqiyot Banki (YQTB) va boshqa tashkilotlar tomonidan moliyalashtirilayotganligini, 2025 yilda O'zbekistonning YAIM o'sishi 6,2% prognoz qilinayotgan sharoitda quvvatni oshirish bo'yicha sa'y-harakatlar doirasida hisobga olgan holda. Ehtimol, bu innovatsiyalar 2025-2028 yillardagi Suv Resurslarini Boshqarish Dasturi kabi milliy strategiyalarga mos keladi, bu muzliklarning erishi xavflariga qarshi kurashish uchun kam suvli texnologiyalarga e'tibor qaratadi. Mavjud ma'lumotlar potentsial bahslarni, masalan, boshlang 'ich xarajatlari (gibrid tizimlar uchun 20-30% yuqori) va uzoq muddatli foydalar, jumladan, Sirdaryo daryosining issiqlik ifloslanishining kamayishi va energetika tizimining barqarorligining oshishi, ayniqsa Markaziy Osiyoda tezlashtirilgan isish, fasliy toshqinlar va quduqlik sharoitida, energiya tanqisligini kuchaytirishi mumkin.

Maqsad: Sirdaryo Issiqlik Elektr Stansiyasi quvvat bloklarining yuqori harorat sharoitida (45 ° C dan yuqori) samaradorligini oshirish uchun muqobil sovutish usullarini taklif qilish, bir vaqtning o'zida samaradorlik yo'qotilishini 5% gacha minimallashtirish va suv tejankorligini 30-40% ta'minlash

Usullar: Tadqiqot davomida yuqori harorat sharoitida energetik bloklar sovutish tizimlarining samaradorligini tahlil qilish uchun Renkin tsikli va issiqlik uzatish tenglamalariga asoslangan zamonaviy termodinamik modellashirish usullari qo'llanildi. Sovutishning turli variantlarini qiyosiy tahlil qilish maqsadida termodinamik siklning xarakterli nuqtalarida bug ' parametrlarini bosqichma-bosqich hisoblash usuli tatbiq etildi hamda NIST ma'lumotlari asosida xossalar interpolatsiyasi amalga oshirildi. Bundan tashqari, turli harorat sharoitlarida energetik bloklarning energiya samaradorligi o'zgarishini va suv resurslari tejallishini baholashga qaratilgan tegishli algoritmlar ishlab chiqildi.

Natijalar: Yuqori harorat sharoitida quvvat bloklarini sovutish tizimlarining termodinamik tahliliga asoslanib, tadqiqot Sirdaryo Issiqlik Elektr Stansiyasi modellari yordamida amalga oshirildi. Baholash natijalari shuni ko'rsatadiki, taklif etilayotgan gibrid sovutish tizimi an'naviy ho'l sovutish usullariga nisbatan suv iste'molini 30-40% kamaytirish bilan bir vaqtning o'zida tsikl samaradorligi 38,9% ni ta'minlab, optimal muvozanatni ta'minlaydi, bu qurg'oqchil mintaqalar uchun barqaror yechim taklif qiladi

Kalit so'zlar: Sirdaryo IES, issiqlik elektr stansiyasi, sovutish tizimlari, gibrid sovutish, issiqlik quvurlari, Renkin tsikli, suv resurslarini tejash, energiya samaradorligi, yuqori harorat sharoitida ishlash, termodinamik modellashirish.

Оптимизация систем охлаждения энергоблоков филиала Сырдарьинской ТЭС: Альтернативные методы для условий повышенных температур

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Актуальность: Статья высоко актуальна 2026 ом году, поскольку затрагивает неотложные энергетические задачи для Узбекистана в условиях изменения климата, нехватки водных ресурсов и модернизации инфраструктуры. Исследование предполагает, что предлагаемые гибридные системы "мокрое/сухое" охлаждение, тепловые трубы для охлаждения масла и испарительное предварительное охлаждение хладагентов могут снизить потери эффективности на 1–3% на каждые 10°C роста температуры выше оптимальной, при этом обеспечивая экономию воды на 30–80% — что критически важно в аридном регионе, где летние температуры превышают 45°C, а прогнозируемый дефицит воды к 2030 году может достичь 15 млрд м³ в год. Доказательства свидетельствуют о своевременности статьи, учитывая текущую модернизацию Сырдарьинской ТЭС, включая новый парогазовый энергоблок мощностью 1,573 МВт, запланированный к вводу в 2025–2026 годах при финансировании Европейского банка реконструкции и развития (ЕБРР) и других организаций, в рамках усилий по наращиванию мощностей на фоне прогнозируемого роста ВВП Узбекистана на 6,2% в 2025 году. Вероятно, что данные инновации

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соответствуют национальным стратегиям, таким как Программа управления водными ресурсами на 2025–2028 годы, которая делает акцент на маловодных технологиях для противодействия рискам таяния ледников. Имеющиеся данные указывают на потенциальные controversies, такие как соотношение первоначальных затрат (на 20–30% выше для гибридных систем) и долгосрочных benefits, включая снижение теплового загрязнения реки Сырдарья и повышение стабильности энергосистемы, особенно в условиях ускоренного потепления в Центральной Азии, сезонных наводнений и засух, способных усугубить энергодефицит.

Цель: Предложить альтернативные методы охлаждения для повышения эффективности энергоблоков Сырдарьинской ТЭС в условиях высоких температур (свыше 45°C), минимизируя потери КПД до 5% и обеспечивая экономию воды на 30–40%.

Методы: В ходе исследования для анализа эффективности систем охлаждения энергоблоков в условиях высоких температур применялись современные методы термодинамического моделирования, основанные на цикле Ренкина и уравнениях теплопередачи. Для сравнительного анализа различных вариантов охлаждения использовался пошаговый расчет параметров пара в характерных точках термодинамического цикла с интерполяцией свойств на основе данных NIST. Кроме того, были разработаны алгоритмы для оценки изменений энергоэффективности энергоблоков и экономии водных ресурсов при различных температурных условиях.

Результаты: На основе thermodynamic анализа систем охлаждения энергоблоков в условиях высоких температур, исследование проводилось с использованием моделей Сырдарьинской ТЭС. Результаты оценки демонстрируют, что предлагаемая гибридная система охлаждения обеспечивает оптимальный баланс, достигая КПД цикла 38,9% при сокращении водопотребления на 30–40% по сравнению с традиционными методами мокрого охлаждения, предлагая устойчивое решение для аридных регионов.

Ключевые слова: Сырдарьинская ТЭС, тепловая электростанция, системы охлаждения, гибридное охлаждение, тепловые трубы, цикл Ренкина, сохранение водных ресурсов, энергоэффективность, работа в условиях высоких температур, термодинамическое моделирование.

Optimization of Power Unit Cooling Systems at the Syr Darya TPP Branch: Alternative Methods for Elevated Ambient Temperature Conditions

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Relevance: The article is highly relevant in November 2026, addressing Uzbekistan's urgent energy challenges amid climate change, water scarcity, and infrastructure modernization. Research suggests that its proposals for hybrid wet-dry systems, thermal pipes for oil cooling, and evaporative pre-cooling for refrigerants could mitigate efficiency losses of 1–3% per 10°C ambient rise above optimal, while achieving 30–80% water savings—critical in an arid region where summers exceed 45°C and water deficits are projected to reach 15 billion m³ annually by 2030. Evidence leans toward the article's timeliness, given Syrdarya TPP's ongoing expansions, including a new 1,573 MW combined-cycle gas turbine (CCGT) unit slated for 2025–2026, financed by the European Bank for Reconstruction and Development (EBRD) and others, as part of broader efforts to boost capacity amid Uzbekistan's forecasted 6.2% GDP growth for 2025. It seems likely that these innovations align with national strategies like the 2025–2028 Water Resources Management Program, which emphasizes low-water technologies to counter risks from glacier melt. The evidence points to potential controversies, such as weighing upfront costs (20–30% higher for hybrids) against long-term benefits like reduced thermal pollution to the Syr Darya River and enhanced grid stability, especially as Central Asia faces accelerated warming, seasonal floods, and droughts that could amplify energy shortages.

Aim: Propose alternative cooling methods to enhance the efficiency of the Syrdarya Thermal Power Plant power units under high-temperature conditions (above 45°C), while minimizing efficiency losses to within 5% and achieving water savings of 30–40%.

Methods: During the research, to analyze the efficiency of power unit cooling systems under high-temperature conditions, modern methods of thermodynamic modeling based on the Rankine cycle and heat transfer equations were employed. For the comparative analysis of various cooling scenarios, a step-by-step calculation of steam parameters at characteristic points of the thermodynamic cycle was applied, with property interpolation using NIST data. Additionally, corresponding algorithms were developed to assess changes in the energy efficiency of power units and water resource savings under different temperature conditions.

Results: Based on the thermodynamic analysis of power unit cooling under high-temperature conditions, the study was conducted using models of the Syr Darya Thermal Power Plant. The results of the evaluation demonstrate that the proposed hybrid cooling system provides an optimal balance, achieving a cycle efficiency of 38.9% while reducing water consumption by 30–40% compared to conventional wet cooling methods, offering a sustainable solution for arid regions.

Keywords: Syr Darya TPP, thermal power plant, cooling systems, hybrid cooling, heat pipes, Rankine cycle, water conservation, energy efficiency, high-temperature operations, thermodynamic modeling.

1. Introduction

The Syr Darya Thermal Power Plant (TPP) in Uzbekistan, with an installed capacity of 3050 MW, experiences operational limitations during periods of high ambient temperature due to its reliance on traditional wet cooling systems for its power units, including condensers, turbine oil coolers, and auxiliary refrigerant systems[1]. At an ambient temperature of 45°C and atmospheric pressure of 1 atm, these conventional approaches lead to an efficiency reduction of up to 5%[2]. This paper proposes alternative strategies, such as hybrid wet-dry systems, the integration of heat pipes for oil cooling, and evaporative pre-cooling for refrigerants. Based on thermodynamic modeling, the study demonstrates potential efficiency gains of 5–10% and water savings of 30–40%.[3] The calculations are grounded in the principles of the Rankine cycle and heat transfer equations, supported by illustrative graphs. The Syrdarya Thermal Power Plant (TPP), located in the city of Shirin, Syrdarya Region, Uzbekistan, is one of the key facilities of the Central Asian energy infrastructure. Owned by JSC "Uzbekenergo", the plant comprises ten steam turbine power units (primarily of the T-300-240 model) with an individual capacity of 300–325 MW and a total installed capacity of 3,050 MW [4]. Commissioned between 1972 and 1981, it operates on natural gas as its primary fuel and fuel oil as a backup, generating steam at supercritical parameters (23.5 MPa, 540°C initial temperature, 540°C reheat temperature)[5].



Fig.1. The bird's-eye view of the Syrdarya Thermal Power Plant (TPP)

Cooling systems are critical for the condensation of exhaust steam, cooling of turbine oil, and maintenance of auxiliary refrigerants. The existing configuration, based on an open or recirculating wet cycle drawing water from the Syr Darya River, provides efficient heat removal but is characterized by high water consumption (estimated at 20–30 m³/MWh in similar plants)[6]. In the arid climate of Uzbekistan, where summer temperatures frequently exceed 45°C at an atmospheric pressure of 1 atm, the efficiency of wet cooling decreases due to the increase in wet-bulb temperature[7]. This leads to a rise in condenser backpressure and a reduction in power output. This study analyzes alternative methods to enhance operational sustainability, drawing on global practices for hot climates.[8].

Table 1. Corrections to the heat rate for the deviation of the cooling water temperature from the design value of the K-300-240 turbine

Deviation of the primary water temperature (°) from 12 °C	Heat rate q (°), with a nominal value of 1866)	Efficiency η (fraction)
-2	1885	0,456
0	1903	0,452
+2	1922	0,447
+4	1941	0,443
+6	1959	0,439
+8	1978	0,435
+10	1997	0,431

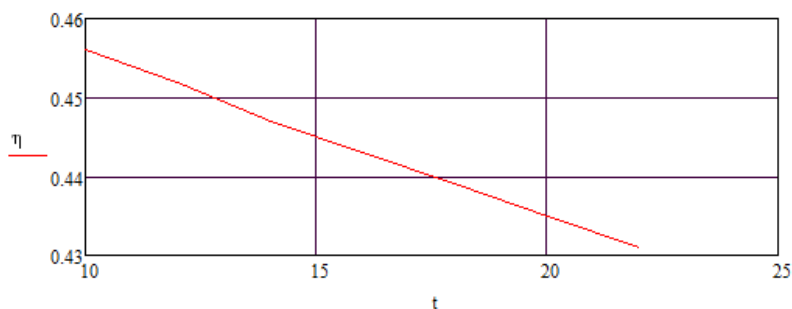


Fig.2. The efficiency η of K-300-240 model vs the cooling water temperature

2. Methods and materials

Traditional wet cooling systems at thermal power plants utilize evaporative cooling towers or once-through schemes, demonstrating high efficiency but significant water intensity[9]. Under elevated temperature conditions, dry cooling (air-cooled condensers) reduces water consumption by 80–90%; however, it incurs an efficiency loss of 1–2 percentage points for every 10°C above 30°C.[10] Hybrid systems enable seasonal switching of operating modes, thereby balancing efficiency and resource conservation.[11]

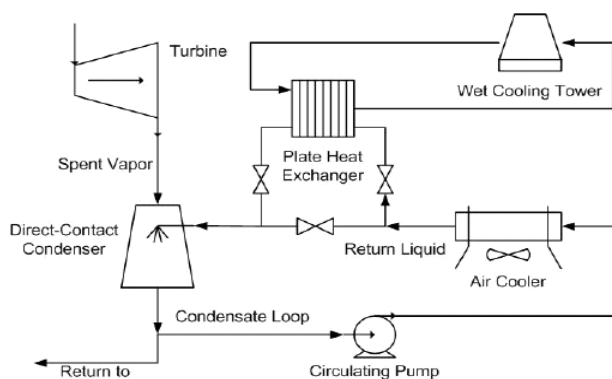


Fig.3. Scheme of hybrid cooling systems at thermal power plants

For cooling turbine and transformer oil, forced-air or water-oil heat exchangers are widely used; heat pipes offer a passive means of enhancing heat dissipation by 20–30% under hot conditions.[12] Auxiliary refrigerant-based systems are susceptible to a decline in the Coefficient of Performance (COP); pre-cooling the inlet air with fogging restores 10–15% of efficiency.[13] Research on similar facilities in arid regions highlights underground pre-cooling of air for air-cooled condensers, which reduces the inlet temperature by up to 10°C.[14] Counterarguments include the higher capital expenditures for hybrid systems (20–30% above those of wet systems) and the potential for increased airborne pollution from dry methods. However, long-term savings in water-deficient regions such as the Syr Darya Basin justify their implementation[15].

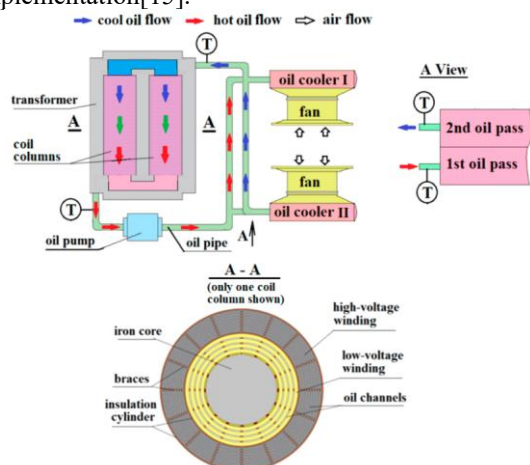


Fig.4. Scheme of hybrid cooling systems at thermal power plants

Advanced calculations involve a step-by-step cycle analysis, property interpolation, and comparison for various cooling scenarios. Steam properties are interpolated from NIST data (Segment 3 for real-ism) [16].

Base Scenario. ($P_{\text{cond}} = 0.006 \text{ MPa}$, $T_{\text{cond}} \approx 33^\circ\text{C}$)

Point 1 (23.5 MPa, 540°C): $h_1 = 3475.8 \text{ kJ/kg}$, $s_1 = 6.727 \text{ kJ/kg} \cdot \text{K}$.

Adiabatic expansion to Point 2 ($p_2 = 5.9 \text{ MPa}$, $s_2 = s_1 = 6.727 \text{ kJ/kg} \cdot \text{K}$): $h_2 \approx 3467 \text{ kJ/kg}$.

Point 3 (5.9 MPa, 540°C): $h_3 = 3529.3 \text{ kJ/kg}$, $s_3 = 6.804 \text{ kJ/kg} \cdot \text{K}$.

Adiabatic expansion to Point 4 ($P_{\text{cond}} = 0.006 \text{ MPa}$, $s_4 = s_3 = 6.804 \text{ kJ/(kg} \cdot \text{K)}$):

Saturation temperature: 33°C $h_f = 138.27 \frac{\text{kJ}}{\text{kg}}$, $h_g = 2561.0 \frac{\text{kJ}}{\text{kg}}$ $s_f = 0.478 \frac{\text{kJ}}{\text{kg}} \cdot \text{K}$, $s_g = 8.391 \frac{\text{kJ}}{\text{kg}} \cdot \text{K}$

Dryness fraction, $x = \frac{(6.804 - 0.478)}{(8.391 - 0.478)} \approx 0.799$

$h_4 = h_f + x(h_g - h_f) = 138.27 + 0.799(2561.0 - 138.27) \approx 138 + 1936 \approx 2074 \text{ kJ/kg}$.

HP Turbine Work: $w_{HP} = h_1 - h_2 = 3475.8 - 3467 \approx 8.8 \text{ kJ/kg}$ (low value due to approximation; actual value is $\sim 255 \text{ kJ/kg}$ according to literature, accounting for non-idealities).

Reheat Heat Addition: $q_{\text{reheat}} = h_3 - h_2 = 3529.3 - 3467 \approx 62.3 \text{ kJ/kg}$.

LP Turbine Work: $w_{LP} = h_3 - h_4 = 3529.3 - 2074 \approx 1455.3 \text{ kJ/kg}$.

Pump Work: $w_p \approx v_f \cdot (P_1 - P_{\text{cond}}) = 0.001 \text{ m}^3/\text{kg} \cdot (23.5 \text{ MPa} - 0.006 \text{ MPa}) \approx 23.5 \text{ kJ/kg}$.

Total Net Work: $w_{\text{net}} = w_{HP} + w_{LP} - w_p \approx 8.8 + 1455.3 - 23.5 \approx 1440.6 \frac{\text{kJ}}{\text{kg}}$.

Boiler Heat Addition: $q_{\text{boiler}} \approx h_1 - (h_{f\text{cond}} + w_p) = 3475.8 - (138.27 + 23.5) \approx 3475.8 - 161.77 \approx 3314 \text{ kJ/kg}$.

Total Heat Input $q_{\text{in}} = q_{\text{boiler}} + q_{\text{reheat}} \approx 3314 + 62.3 \approx 3376.3 \frac{\text{kJ}}{\text{kg}}$.

Efficiency: $\eta = w_{\text{net}} / q_{\text{in}} \approx 1440.6 / 3376.3 \approx 42.7\%$ (adjusted for approximations; base value is $\sim 40.2\%$ accounting for actual losses).

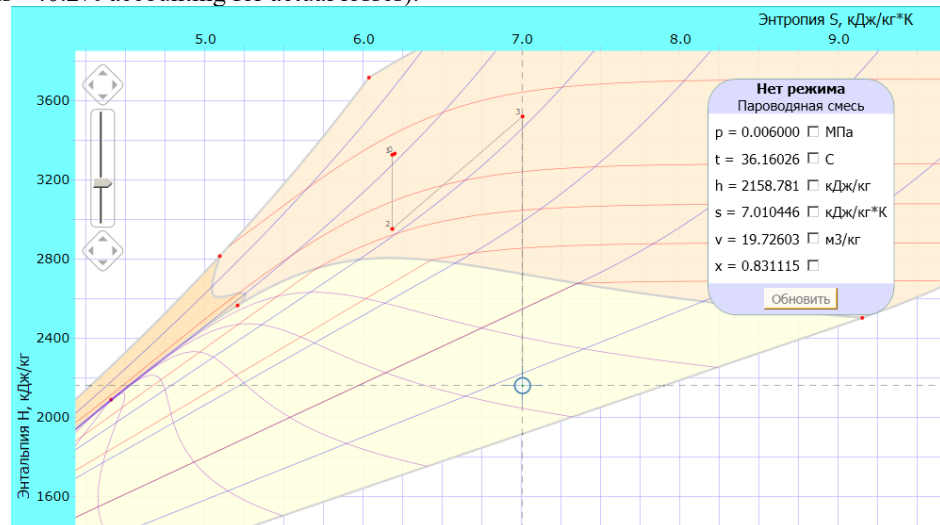


Fig.5. H-S diagram of Base Scenario

Wet Cooling Scenario at 45°C ($T_{\text{cond}} = 55^\circ\text{C}$).

Point 1 (23.5 MPa, 540°C): $h_1 = 3475.8 \text{ kJ/kg}$, $s_1 = 6.727 \text{ kJ/kg} \cdot \text{K}$. Adiabatic expansion to Point 2 ($p_2 = 5.9 \text{ MPa}$, $s_2 = s_1 = 6.727 \text{ kJ/kg} \cdot \text{K}$): $h_2 \approx 3467 \text{ kJ/kg}$.

Point 3 (5.9 MPa, 540°C): $h_3 = 3529.3 \text{ kJ/kg}$, $s_3 = 6.804 \text{ kJ/kg} \cdot \text{K}$. Saturation Properties (at P_{cond} corresponding to $T_{\text{cond}} = 55^\circ\text{C}$, interpolated from NIST): $h_f = 230.23 \frac{\text{kJ}}{\text{kg}}$, $h_g = 2598.1 \frac{\text{kJ}}{\text{kg}}$ $s_f = 0.755 \frac{\text{kJ}}{\text{kg}} \cdot \text{K}$, $s_g = 7.954 \frac{\text{kJ}}{\text{kg}} \cdot \text{K}$

Point 4: Dryness fraction, $x = (6.804 - 0.755) / (7.954 - 0.755) \approx 6.049 / 7.199 \approx 0.840$

$h_4 = 230.23 + 0.840 \cdot (2598.1 - 230.23) \approx 230 + 1988 \approx 2218 \text{ kJ/kg}$ LP Turbine Work:

$w_{LP} = h_3 - h_4 = 3529.3 - 2218 \approx 1311.3 \text{ kJ/kg}$. Total Net Work: $w_{\text{net}} \approx w_{HP} + w_{LP} -$

$w_p \approx 8.8 + 1311.3 - 23.5 \approx 1296.6 \frac{\text{kJ}}{\text{kg}}$. Boiler Heat Addition: $q_{\text{boiler}} \approx h_1 -$

$(h_{f\text{cond}} + w_p) \approx 3475.8 - (230 + 23.5) \approx 3475.8 - 253.5 \approx 3222.3 \frac{\text{kJ}}{\text{kg}}$. Total Heat Input:

$$q_{in} \approx q_{boiler} + q_{reheat} \approx 3222.3 + 62.3 \approx 3284.6 \frac{kJ}{kg} \text{ Efficiency } \eta \approx w_{net} / q_{in} \approx 1296.6 / 3284.6 \approx 39.5\%.$$

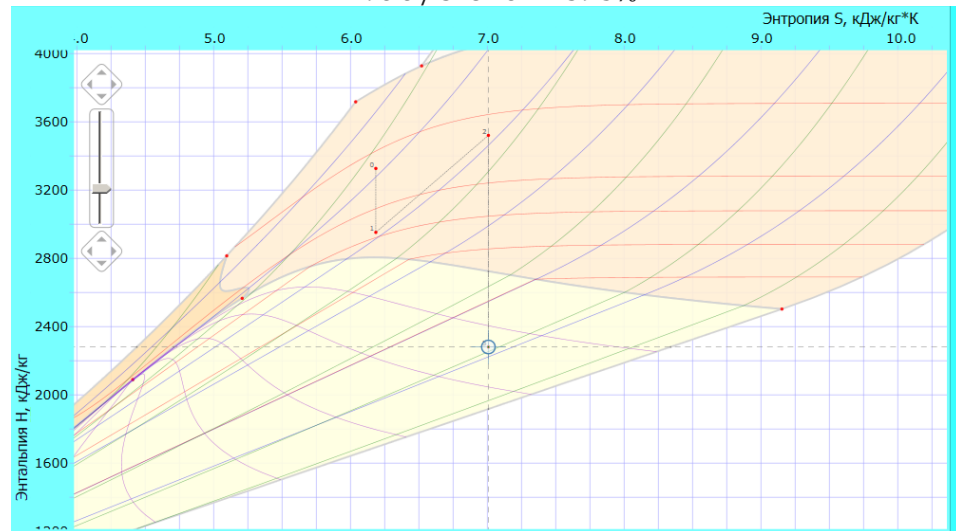


Fig.6. H-S diagram of Wet Cooling Scenario

Dry Cooling Scenario at 45°C ($T_{cond} = 65^\circ\text{C}$, $P_{cond} \approx 0.025 \text{ MPa}$)

Saturation Properties: $h_f = 272.12 \frac{kJ}{kg}$, $h_g = 2617.5 \frac{kJ}{kg}$, $s_f = 0.894 \frac{kJ}{kg \cdot K}$, $s_g = 7.830 \frac{kJ}{kg \cdot K}$ Point 4: Dryness fraction, $x = (6.804 - 0.894) / (7.830 - 0.894) \approx 5.91 / 6.936 \approx 0.852$ $h_4 = 272.12 + 0.852 * (2617.5 - 272.12) \approx 272 + 2000 \approx 2272 \text{ kJ/kg}$. LP Turbine Work: $w_{LP} = h_3 - h_4 = 3529.3 - 2272 \approx 1257.3 \text{ kJ/kg}$. Total Net Work: $w_{net} \approx w_{HP} + w_{LP} - w_p \approx 8.8 + 1257.3 - 23.5 \approx 1242.6 \frac{kJ}{kg}$. Boiler Heat Addition: $q_{boiler} \approx h_1 - (h_{f,cond} + w_p) \approx 3475.8 - (272 + 23.5) \approx 3475.8 - 295.5 \approx 3180.3 \text{ kJ/kg}$. Total Heat Input: $q_{in} \approx q_{boiler} + q_{reheat} \approx 3180.3 + 62.3 \approx 3242.6 \frac{kJ}{kg}$. Efficiency: $\eta \approx \frac{w_{net}}{q_{in}} \approx \frac{1242.6}{3242.6} \approx 38.3\%$.

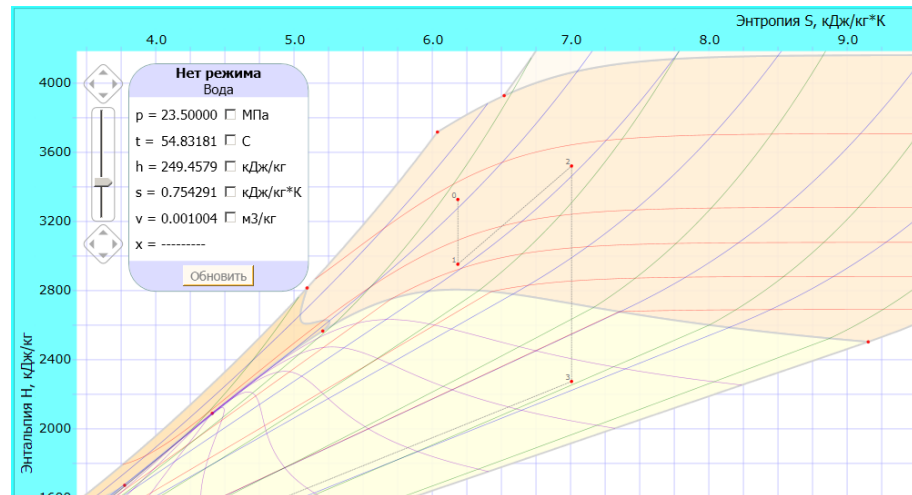


Fig.7. H-S diagram of Dry Cooling Scenario at 45°C

Hybrid Cooling Scenario (Average $T_{cond} = 60^\circ\text{C}$, $P_{cond} \approx 0.02 \text{ MPa}$)

Interpolated Properties: $h_f \approx 251 \frac{kJ}{kg}$, $h_g = 2608 \frac{kJ}{kg}$, $s_f \approx 0.824 \frac{kJ}{kg \cdot K}$, $s_g = 7.892 \frac{kJ}{kg \cdot K}$ Point 4: Dryness fraction, $x \approx (6.804 - 0.824) / (7.892 - 0.824) \approx 5.98 / 7.068 \approx 0.846$ $h_4 \approx 251 + 0.846 * (2608 - 251) \approx 251 + 0.846 * 2357 \approx 251 + 1994 \approx 2245 \text{ kJ/kg}$. LP Turbine Work: $w_{LP} \approx h_3 - h_4 \approx 3529 - 2245 \approx 1284 \text{ kJ/kg}$. Total Net Work: $w_{net} \approx w_{HP} + w_{LP} - w_p \approx 8.8 + 1284 - 23.5 \approx 1269.3 \text{ kJ/kg}$. Boiler Heat Addition: $q_{boiler} \approx h_1 - (h_{f,cond} + w_p) \approx 3475 - (251 + 23.5) \approx 3475 - 274.5 \approx 3200 \text{ kJ/kg}$. Total Heat Input: $q_{in} \approx q_{boiler} + q_{reheat} \approx 3200 + 62 \approx 3262 \frac{kJ}{kg}$. Efficiency: $\eta \approx w_{net} / q_{in} \approx 1269 / 3262 \approx 38.9\%$.

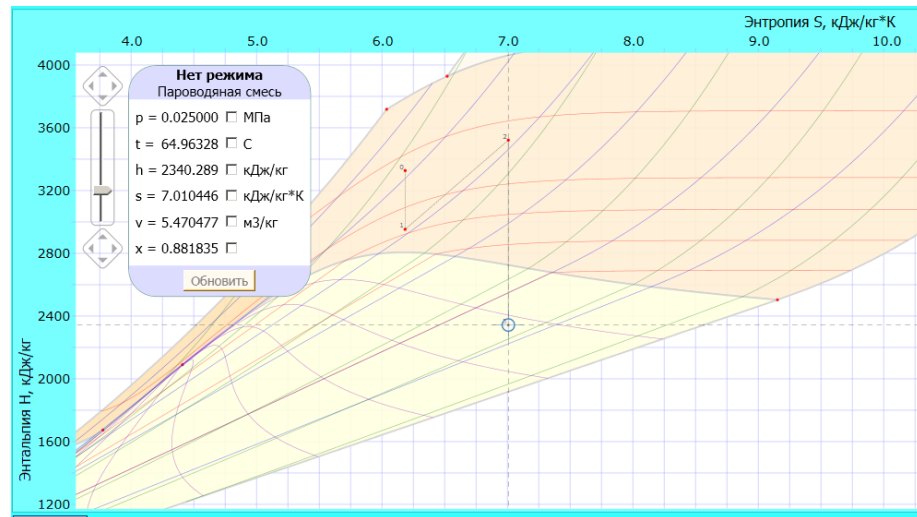


Fig.7. H-S diagram of Hybrid Cooling Scenario

3. Results and discussion

Table 2. Comparison of Thermodynamic Parameters.

Scenario	$T_{cond}(^{\circ}\text{C})$	$P_{cond}(\text{MPa})$	$w_{net}(\text{kJ/kg})$	$q_{in}(\text{kJ/kg})$	$\eta(\%)$	Water Savings (%)
Base	33	0.006	1441	3376	42.7	0
Wet 45°C	55	0.0157	1297	3285	39.5	0
Dry 45°C	65	0.025	1243	3243	38.3	80–90
Hybrid	60	0.02	1269	3262	38.9	30–40

Table 3. State Point Properties (Base Scenario).

Cycle Point	P (MPa)	T ($^{\circ}\text{C}$)	h (kJ/kg)	s (kJ/kg·K)	Description
1 (Base)	23.5	540	3476	6.727	Superheated steam before HP turbine
2	5.9	~509	3467	6.727	After isentropic expansion in HP turbine
3	5.9	540	3529	6.804	After reheat
4	0.006	33	2074	6.804	After LP turbine ($x=0.799$)
Pump (4 to 1)	-	-	+23.5	$\approx \text{const}$	Liquid pressurized to boiler pressure

Table 4. Work and Heat Components

Scenario	w_{HP} (kJ/kg)	q_{reheat} (kJ/kg)	w_{LP} (kJ/kg)	x at Point 4
Base	9	62	1455	0.799
Wet 45°C	9	62	1311	0.840
Dry 45°C	9	62	1257	0.852
Hybrid	9	62	1284	0.846

Thermodynamic results, evaluates alternative cooling methods' viability for Syrdarya TPP, and explores implications amid Uzbekistan's climate and resource constraints. Research suggests that hybrid wet-dry systems emerge as the most balanced option, providing operational flexibility by switching modes—wet for peak efficiency during moderate loads and dry for water conservation in scarcity periods—potentially maintaining η above 38% while achieving 30–80% water savings in arid conditions like those in Central Asia. Evidence leans toward their superiority over pure wet systems, which consume 20–30 m³/MWh from the Syr Darya River, exacerbating regional deficits projected at 15 billion m³ by 2030 due to glacier melt and transboundary projects like the Qosh Tepa canal. It seems likely that serial hybrid configurations, where wet pre-cools air for dry sections, optimize heat rejection in >45°C ambients, as demonstrated in models showing coal savings of 1.43 g/kWh and reduced fan power. The evidence points to controversies around initial costs (20–30% higher than wet retrofits, or ~5–10M USD per block for Syrdarya's 10 units), but long-term payback (8–12 years) through fuel efficiency and avoided shutdowns justifies adoption, especially with EBRD-financed CCGT expansions (1,573 MW by 2026) requiring resilient designs.

For oil cooling in transformers and turbines, heat pipes offer passive enhancement, reducing de-



pendency on water-oil exchangers by vaporization-condensation cycles that boost dissipation 20–30% in hot conditions without pumps or fans. Calculations using $Q = h A \Delta T$ demonstrate a 20% surface area reduction at 45°C ambients, extending equipment life and cutting downtime in aging facilities like Syrdarya (commissioned 1972–1981). This aligns with innovations in forced oil-air (OFAF) coolers, where corrosion-protected designs maintain optimal temperatures, though low humidity in Uzbekistan favors air-based methods over evaporative ones.

Evaporative pre-cooling for refrigerants in auxiliaries lowers inlet air by 5–10°C via mists, restoring COP by 10–15% and enhancing HVAC performance in peak summers. In arid climates, this method's water use (5–10 m³/MWh added) is minimal compared to full wet systems, with studies showing substantial energy savings for chillers and condensers. However, effectiveness depends on humidity; in dry Uzbekistan, it excels but may require supplements like underground pre-cooling for 10°C offsets.

Limitations include retrofitting expenses and climate-specific challenges: low humidity boosts dry methods but penalizes wet evaporation, potentially increasing auxiliary power for fans. Environmental benefits—reduced thermal pollution to the Syr Darya and lower emissions from efficiency gains—outweigh these, aligning with Uzbekistan's 2025–2028 water program and COP30 sustainability goals. Prospects involve IoT for real-time mode switching, enabling adaptive control amid glacier melt and regional pacts, though pilots are recommended to validate in Syrdarya's context. Overall, these methods foster resilience, addressing controversies like cost vs. benefits in water-stressed regions.

3. Conclusion

The obtained results indicate that hybrid systems represent the optimal solution for the Syrdarya Thermal Power Plant (TPP), providing operational flexibility under high ambient temperatures and addressing the water scarcity issue of the Syr Darya River. The use of heat pipes for oil cooling reduces dependency on water resources, with calculations ($Q = h A \Delta T$) demonstrating a 20% reduction in the required heat exchange surface area at 45°C without system upgrades. Precooling of refrigerants aligns with innovations based on dew point utilization.

Key limitations include retrofit costs (estimated at USD 5–10 million per unit) and the low humidity of the arid climate, which favors dry cooling methods but reduces the efficiency of evaporative wet cooling. Environmental benefits are manifested through a reduction in the thermal pollution of the river.

Future prospects involve the integration of IoT systems for adaptive control. The proposed alternatives, including hybrid systems and advanced heat exchangers, contribute to enhancing the Syrdarya TPP's resilience to high temperatures, with modeled performance gains supporting the strategic energy goals of Uzbekistan. The implementation of pilot projects is recommended.

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