DAFTAR PUSTAKA

1. **Incropera, F.P., and De Witt, D.P.** 2011. *“Fundamental of Heat and Mass Transfer Seventh Edition”*. Singapore: John Willey & Sons, Inc.

2. **Kakac, Sadik, and Hongtan Liu.** 2002. *“Heat Exchangers: Selection, Rating, and Thermal Design Second Edition”*. Florida: Department of Mechanical Engineering University of Miami.

3. **Moran, Michael J. and Shapiro, Howard.** 2006. *“Fundamentals of Engineering Thermodynamics 5th Edition”*. New York : John Wiley & Sons, Inc.

4. **Wijanarko, NadiaParwaty**. 2017. *"Re-Design High Pressure Heater (HPH) 5 Unit 1 di PT. PJB UP. Gresik Menggunakan Analisis Termodinamika dan Perpindahan Panas"*. Surabaya : Institut Teknologi Sepuluh Nopember.

5. **Raja, A.K Srivastava, Amit Prakash, Manish**. 2017. *“Power Plant Engineering”*.India : Made Easy

6. **Tsou, J.** 1998. *“Thermal Performance Engineering Handbook”*. Volume II TR-109546. USA : EPRI.

7. **Manufacture, Dongfang**. 2021. *“115 MW Thermodynamic Performance for Model N125-13.24/535/535 Steam Turbine”*. China : SepcoIII Electric Power Construction Co.,Ltd.

8. **Kalbar-1, PLTU 2x100 MW**. 2021. *“Indonesia Kalbar-1 2x100 MW (net) Coal-Fired Power Plant #2 Unit Overall Performance Test Report”*. Kalbar-1 : Qing Dao Huafeng Weiye Eletric Power Technology Engineering Co.,Ltd.Song

9. **Song, JingHui.** 2017 *"Analysis of Optimal Design of Low Temperature Economizer"*. Hebei, Baoding, China : Purpose-LED Publishing

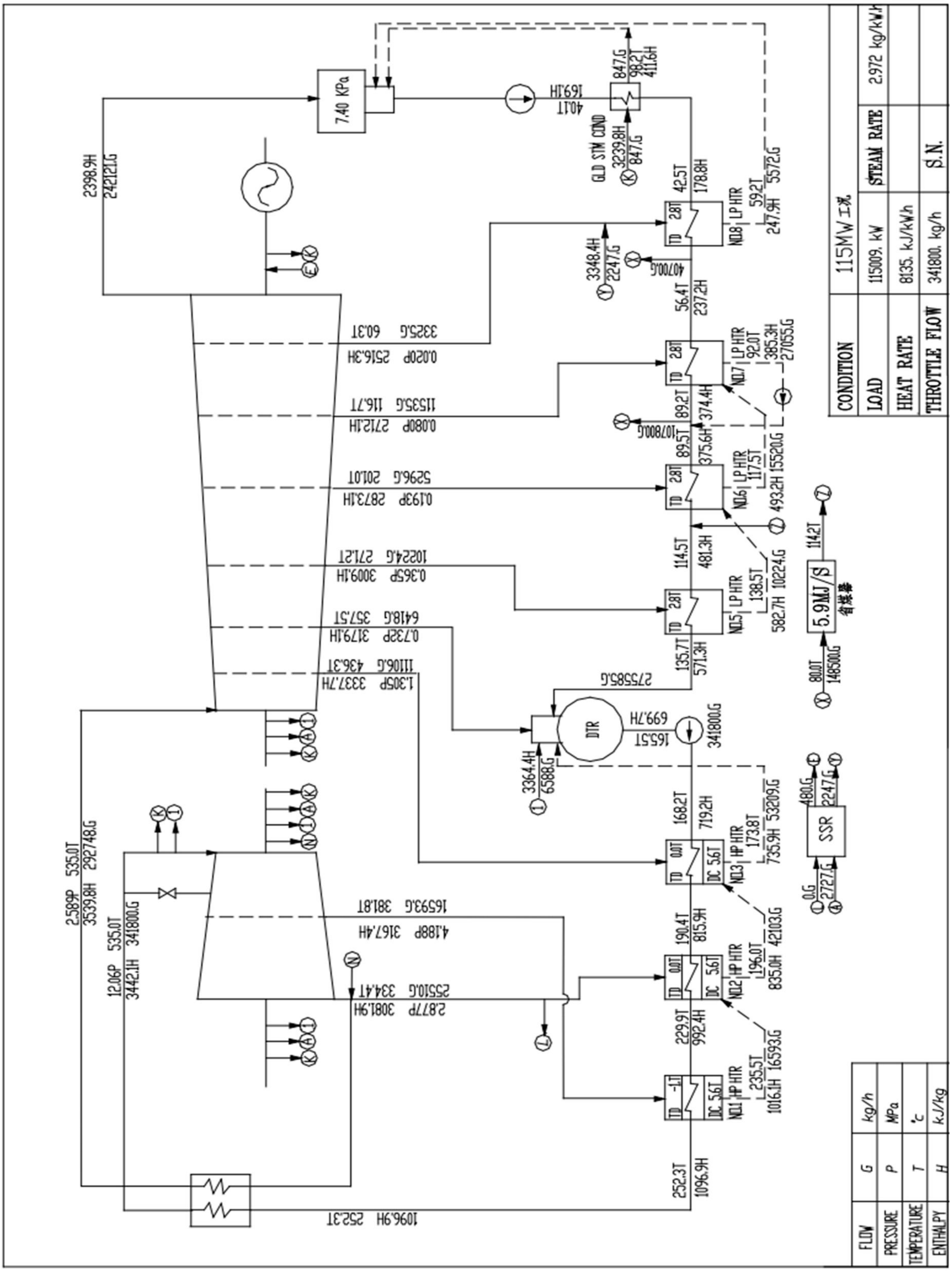
10. **Bhattacharya, Chittatosh and Banerjee, Nilotpa.** 2010. *"Optimizing Boiler Feed Water Inlet Temperature to Maximize Efficiency of Steam Power Plant"* India : ResearchGate

11. **Liu, Jiayou and Sun, Fengzhong**. 2019.*"Experimental Study on Operation Regulation of a Coupled High–Low Energy Flue Gas Waste Heat Recovery System Based on Exhaust Gas Temperature Control"*. China : MDPI

12. **Zhang, Xuwei, Liu, Ming, Ma, Yuegeng and Yan, Junjie**. 2018.*" Thermo-economic analyses on a new conceptual system of waste heat recovery integrated with an S-CO2 cycle for coal-fired power plants"*. Energy Conversion and Management : Elsevier.

13. **Jiang, Long, Hao, Jian, Liu, Gaojun and Cai, XiangDong**. 2017. *"Study on the Influence of Fiber Reinforced Plastics Flue on the Pollutant Emission of Coal-fired Power Plant".* Atlantis Press : Part of Spring Nature

LAMPIRAN I : *Thermodynamic Performance* Beban 115 MW Gross PLTU Kalbar-1



Sumber : *Sepco III Project PLTU Kalbar-1, Model N125-13.24/535/535 Steam Turbine Manufacture By Dongfang*

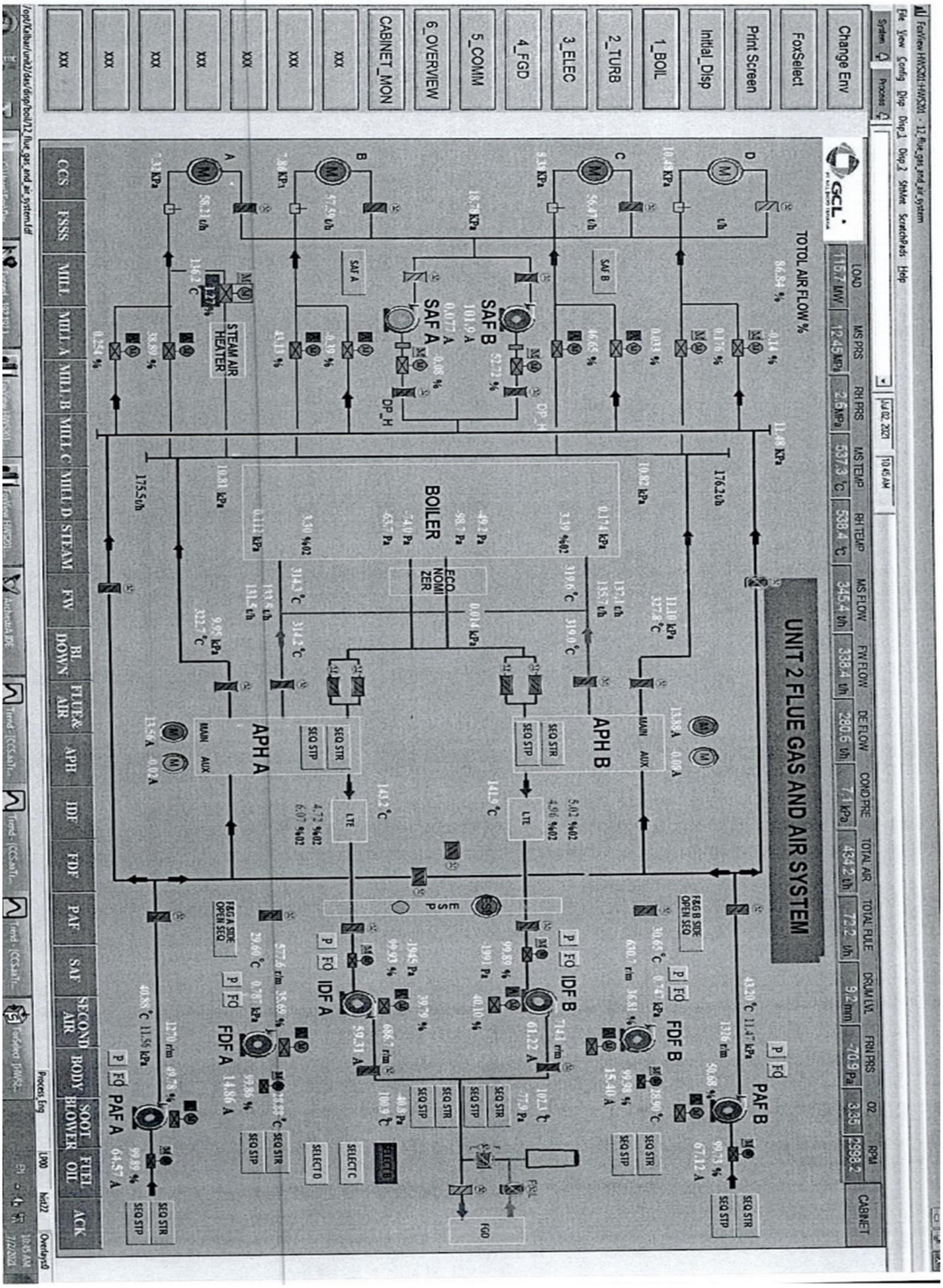
LAMPIRAN II : *Performance Test Result Unit #2* PLTU Kalbar-1

2 号机组性能试验计算结果汇总表 Results Summary of calculation for unit #2 performance test						
试验项目 Test item	单位 Unit	试验工况 VWO	试验工况 TMCR-1	试验工况 TMCR-2	试验工况 100 MW (Net) - 1	试验工况 100 MW (Net) - 2
试验日期 Test date	年 月 日	2021.07.02 19:40-20:40	2021.07.02 16:55-17:55	2021.07.02 17:55-18:55	2021.07.02 09:45-11:45	2021.07.02 12:15-14:15
汽机修正毛热耗率 Correction gross heat rate of steam turbine	kCal/(kW. h)	1931.869	1930.809	1931.501	1946.335	1947.721
锅炉修正效率 Boiler correction efficiency	%	83.570	84.467	84.497	83.99	84.019
管道效率 Pipeline efficiency	%	99.6	99.6	99.6	99.6	99.6
机组毛热耗率 Unit gross heat rate	**kCal/(kW. h)**	**2320.962**	**2317.470**	**2317.968**	**2351.934**	**2346.859**
修正后毛功率 Gross power after correction	**MW**	**134.354**	**127.679**	**128.363**	**115.060**	**115.414**
辅助设备的功率损耗测量值 The power consumption of the measuring auxiliary equipment	MW	9.403	9.351	9.213	8.648	8.722
主变压器损耗 Main transformer losses	kW	330.361	306.933	309.862	267.467	237.185
励磁功率 Excitation power	MW	0.197	0.184	0.189	0.167	0.169
总厂用电耗 Total auxiliary power	**MW**	**9.930**	**9.842**	**9.712**	**9.082**	**9.127**
总厂用电率 Average value of actual plant power consumption rate	%	7.563	7.845	7.690	7.854	7.850
煤耗 Average coal consumption of power supply unit	g/(kW. h)	323.322	323.241	332.563	325.799	326.155

2 号机组性能试验计算结果汇总表 Results Summary of calculation for unit #2 performance test						
试验项目 Test item	单位 Unit	试验工况 VWO	试验工况 TMCR-1	试验工况 TMCR-2	试验工况 100 MW (Net) - 1	试验工况 100 MW (Net) - 2
净功率 Net power output	**MW**	**124.424**	**117.837**	**118.651**	**105.977**	**106.287**
机组净热耗率 Unit net heat rate	**kCal/(kW. h)**	**2506.200**	**2511.029**	**2507.699**	**2553.500**	**2548.391**

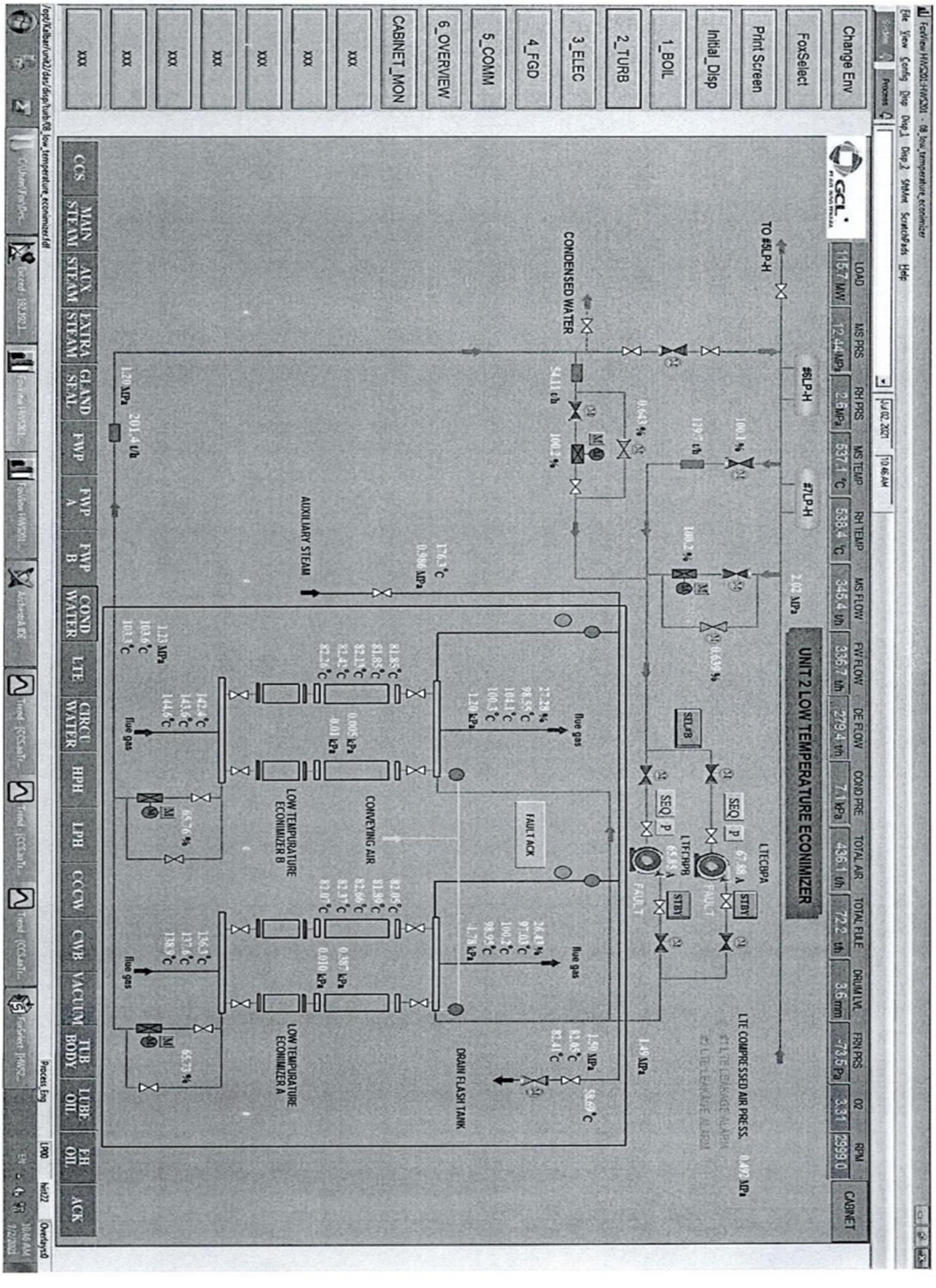
Sumber : Indonesia Kalbar-1 2x100MW (Net) *Coal – Fired Power Plant #2 Unit Overall Performance Test Report by QingDaoHuafengWeiye Electric Power Technology Engineering Co.,Ltd Testing Center*, 2021

LAMPIRAN III *: Flue Gas Display* pada *Performance Test Unit #2* PLTU Kalbar-1



Sumber : Indonesia Kalbar-1 2x100MW (Net) *Coal – Fired Power Plant #2 Unit Overall Performance Test Report by QingDaoHuafengWeiye Electric Power Technology Engineering Co.,Ltd Testing Center*, 2021

LAMPIRAN IV *: LTE Display* pada *Performance Test Unit #2* PLTU Kalbar-1



Sumber : Indonesia Kalbar-1 2x100MW (Net) *Coal – Fired Power Plant #2 Unit Overall Performance Test Report by QingDaoHuafengWeiye Electric Power Technology Engineering Co.,Ltd Testing Center*, 2021

LAMPIRAN V : *Power Input for Induced Draught Fan*

$$\text{Power Input} = \int mVdp = \frac{m_f \times \frac{A}{F} \times v_a \times \Delta p}{\eta_{FD}} \text{kW} = \frac{m_f \times \frac{A}{F} \Delta p}{\rho_{air} \times \eta_{FD}} \text{ kW}$$

η_{FD} = Efficiency of forced draught fan and.

A/F = air-fuel ratio

For good reliability, two forced draught fans operating in parallel are normally used, each capable of undertaking at least 60% of full load air flow, when the other is out of service.

The forced draught fan maintains the entire system up to the stack entrance under positive gauge pressure. The furnace is said to be pressurized.

The stack in such situation is shorter and meant only for disposal of flue gases.

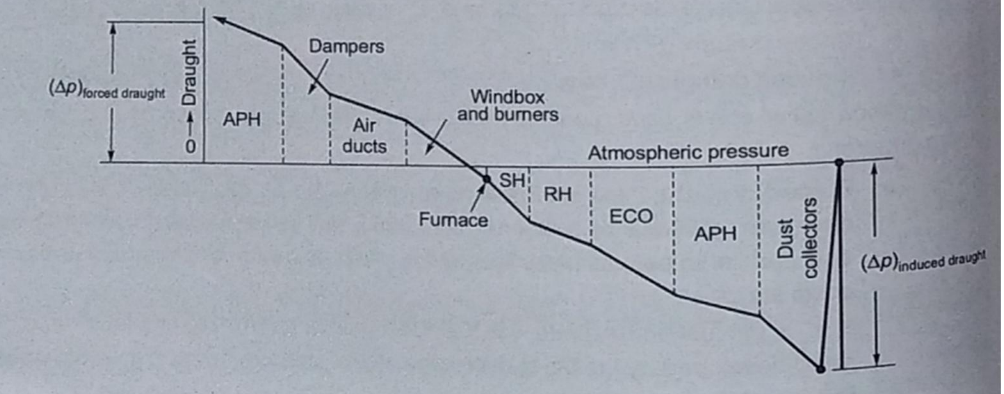
(b) **Induced draught:** Fans are normally located at the **foot of the stack**. They handle **hot combustion gases**. There power requirements are, therefore, greater than forced draught fans. In addition they must cope with corrosive combustion product and fly ash. Induced draught fans are seldom used alone. They discharge essentially at atmospheric pressure and place the system upstream under negative gauge pressure.

If v_g is the specific volume of the flue gases handled by the ID fan and Δp_{ID} is the pressure head developed, then the power needed to drive the ID fan is

$$\text{Power Input} = \int m_g v_g dp = \frac{m_f \times \left(1+\frac{A}{F}\right) \times v_g \times \Delta p_{ID}}{\eta_{ID}} \text{ kW} = \frac{m_f \left(1+\frac{A}{F}\right) \Delta p_{ID}}{\rho_g \times \eta_{ID}} \text{ kW}$$

NOTE

When both forced and induced draught fans are used in a steam generator, the FD fans push atmospheric air through the air preheater, dampers, various air ducts and burners into the furnace, and ID fans suck out the flue gases through the heat transfer surfaces in the superheaters, reheaters, economiser, gas-side air preheater and dust collectors and discharge into the stack. In such a cases the furnace is said to be operate with balanced draught, meaning that the pressure in it is approximately atmospheric. Actually, it is maintained at a ***slightly negative gauge*** pressure to avoid inward leakage.



Sumber : Power Plant Engineering Raja, A.K Srivastava and Amit Prakash, Manish. 2017.

Lampiran VI : Table A.6 Thermophysical Properties of Saturated Water

TABLE A.6 Thermophysical Properties of Saturated Water[a]

Temperature, T (K)	Pressure, p (bars)[b]	Specific Volume (m³/kg) $v_f \cdot 10^3$	v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	$c_{p,g}$	Viscosity (N · s/m²) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	$k_g \cdot 10^3$	Prandtl Number Pr_f	Pr_g	Surface Tension, $\sigma_f \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta_f \cdot 10^6$ (K⁻¹)	Temperature, T (K)
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2	12.99	0.815	75.5	−68.05	273.15
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3	12.22	0.817	75.3	−32.74	275
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6	10.26	0.825	74.8	46.04	280
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9	8.81	0.833	74.3	114.1	285
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3	7.56	0.841	73.7	174.0	290
295	0.02617	1.002	51.94	2449	4.181	1.868	959	8.89	606	19.5	6.62	0.849	72.7	227.5	295
300	0.03531	1.003	39.13	2438	4.179	1.872	855	9.09	613	19.6	5.83	0.857	71.7	276.1	300
305	0.04712	1.005	29.74	2426	4.178	1.877	769	9.29	620	20.1	5.20	0.865	70.9	320.6	305
310	0.06221	1.007	22.93	2414	4.178	1.882	695	9.49	628	20.4	4.62	0.873	70.0	361.9	310
315	0.08132	1.009	17.82	2402	4.179	1.888	631	9.69	634	20.7	4.16	0.883	69.2	400.4	315
320	0.1053	1.011	13.98	2390	4.180	1.895	577	9.89	640	21.0	3.77	0.894	68.3	436.7	320
325	0.1351	1.013	11.06	2378	4.182	1.903	528	10.09	645	21.3	3.42	0.901	67.5	471.2	325
330	0.1719	1.016	8.82	2366	4.184	1.911	489	10.29	650	21.7	3.15	0.908	66.6	504.0	330
335	0.2167	1.018	7.09	2354	4.186	1.920	453	10.49	656	22.0	2.88	0.916	65.8	535.5	335
340	0.2713	1.021	5.74	2342	4.188	1.930	420	10.69	660	22.3	2.66	0.925	64.9	566.0	340
345	0.3372	1.024	4.683	2329	4.191	1.941	389	10.89	668	22.6	2.45	0.933	64.1	595.4	345
350	0.4163	1.027	3.846	2317	4.195	1.954	365	11.09	668	23.0	2.29	0.942	63.2	624.2	350
355	0.5100	1.030	3.180	2304	4.199	1.968	343	11.29	671	23.3	2.14	0.951	62.3	652.3	355
360	0.6209	1.034	2.645	2291	4.203	1.983	324	11.49	674	23.7	2.02	0.960	61.4	697.9	360
365	0.7514	1.038	2.212	2278	4.209	1.999	306	11.69	677	24.1	1.91	0.969	60.5	707.1	365
370	0.9040	1.041	1.861	2265	4.214	2.017	289	11.89	679	24.5	1.80	0.978	59.5	728.7	370
373.15	1.0133	1.044	1.679	2257	4.217	2.029	279	12.02	680	24.8	1.76	0.984	58.9	750.1	373.15
375	1.0815	1.045	1.574	2252	4.220	2.036	274	12.09	681	24.9	1.70	0.987	58.6	761	375
380	1.2869	1.049	1.337	2239	4.226	2.057	260	12.29	683	25.4	1.61	0.999	57.6	788	380
385	1.5233	1.053	1.142	2225	4.232	2.080	248	12.49	685	25.8	1.53	1.004	56.6	814	385
390	1.794	1.058	0.980	2212	4.239	2.104	237	12.69	686	26.3	1.47	1.013	55.6	841	390
400	2.455	1.067	0.731	2183	4.256	2.158	217	13.05	688	27.2	1.34	1.033	53.6	896	400
410	3.302	1.077	0.553	2153	4.278	2.221	200	13.42	688	28.2	1.24	1.054	51.5	952	410
420	4.370	1.088	0.425	2123	4.302	2.291	185	13.79	688	29.8	1.16	1.075	49.4	1010	420
430	5.699	1.099	0.331	2091	4.331	2.369	173	14.14	685	30.4	1.09	1.10	47.2		430

Sumber : Fundamental of Heat and Mass Transfer Sixth Edition

Lampiran VII : Tabel A.3 Properties of Saturated Water (Liquid – Vapor): Pressure Table

TABLE A-3 Properties of Saturated Water (Liquid–Vapor): Pressure Table

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949	0.90
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594	1.00
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959	4.00
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212	5.00
6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600	6.00
7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00
8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628	8.00
9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226	9.00
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448	15.0
20.0	212.4	1.1767	0.09963	906.44	2600.3	908.79	1890.7	2799.5	2.4474	6.3409	20.0
25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1841.0	2803.1	2.5547	6.2575	25.0
30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1795.7	2804.2	2.6457	6.1869	30.0
35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1753.7	2803.4	2.7253	6.1253	35.0
40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7964	6.0701	40.0
45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199	45.0
50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734	50.0
60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892	60.0
70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2772.1	3.1211	5.8133	70.0
80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2758.0	3.2068	5.7432	80.0
90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2742.1	3.2858	5.6772	90.0
100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3596	5.6141	100.
110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2705.6	3.4295	5.5527	110.

TABLE A-3 *(Continued)*

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
120.	324.8	1.5267	0.01426	1473.0	2513.7	1491.3	1193.6	2684.9	3.4962	5.4924	120.
130.	330.9	1.5671	0.01278	1511.1	2496.1	1531.5	1130.7	2662.2	3.5606	5.4323	130.
140.	336.8	1.6107	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6232	5.3717	140.
150.	342.2	1.6581	0.01034	1585.6	2455.5	1610.5	1000.0	2610.5	3.6848	5.3098	150.
160.	347.4	1.7107	0.009306	1622.7	2431.7	1650.1	930.6	2580.6	3.7461	5.2455	160.
170.	352.4	1.7702	0.008364	1660.2	2405.0	1690.3	856.9	2547.2	3.8079	5.1777	170.
180.	357.1	1.8397	0.007489	1698.9	2374.3	1732.0	777.1	2509.1	3.8715	5.1044	180.
190.	361.5	1.9243	0.006657	1739.9	2338.1	1776.5	688.0	2464.5	3.9388	5.0228	190.
200.	365.8	2.036	0.005834	1785.6	2293.0	1826.3	583.4	2409.7	4.0139	4.9269	200.
220.9	374.1	3.155	0.003155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298	220.9

Sumber: Michael J. Moran and Howard Saphiro, 2006

Lampiran VIII : Parameter Impacting Heat Rate

Parameters Impacting Heat Rate

OPERATOR CONTROLLABLE

Parameter	Change	%HR
Outlet Gas Temp (12,000 Btu/lb Coal)	+10 DegF	+.25%
Outlet Gas Temp (8,000 Btu/lb Coal)	+10 DegF	+.35%
Outlet Gas O2	+1%	+.29%
Main Steam Temp (Subcritical Unit)	+10 DegF	-.15%
Main Steam Temp (Supercritical Unit)	+10 DegF	-.20%
Hot Reheat Temp	+10 DegF	-.14%
Main Steam Pressure (Constant Control Valve)	+10 Psi	-.04%
Superheat Spray (From BFP Discharge)	+1% of MSF	+.025%
Superheat Spray (From Final FW)	+1% of MSF	+.008%
Reheat Spray	+1% of MSF	+.20%

PLANT CONTROLLABLE

Condenser Pressure	1"HG	Thermal Kit
Station Service	+1%	+1.0%
Final Feedwater Temp	+5 DegF	-.10%
Unburned Carbon	+1%	+1.0%
Steam Coils (From Drum)	+1% of MSF	+.37%
Steam Coils (From Cold Reheat)	+1% of MSF	+.25%

Parameters Impacting Heat Rate

Turbine Cycle Components

Parameter	Change	%HR
HP Turbine Efficiency (Reheat Unit)	+1%	-.18%
HP Turbine Efficiency (Non Reheat Unit)	+1%	-.60%
IP Turbine Efficiency	+1%	-.17%
LP Turbine Efficiency	+1%	-.45%
BFP Efficiency	+1%	-.02%
BFPT Efficiency	+1%	-.02%
Top HP Heater TTD	+5 DegF	+.10%
Other Heaters TTD	+5 DegF	+.03%

Boiler Components

Parameter	Change	%HR
Coal Moisture		
(12,000 Btu/lb Coal)	+1%	+.10%
(8,000 Btu/lb Coal)	+1%	+.17%
Coal Hydrogen		
(12,000 Btu/lb Coal)	+1%	+.80%
(8,000 Btu/lb Coal)	+1%	+1.2%
Air Heater Leakage	+1%	+.05%
Air Heater Effectiveness	+1%	-.15%
FD Fan Inlet Air Temp	+10 DegF	-.05%
Mill Outlet Air Temp	+10 DegF	-.04%

Sumber : Heat Rate Handbook 4th Edition, Southern Company