permanent set. At 2.6 x design working pressure the stiffening ring showed signs of permanent set. On two occasions at 3 x design working pressure, the aluminium gaskets on the joint ring blew out and on another occasion the nuts on the cover studs were found to have become slack after the vessel had been up to this pressure. Finally, the vessel itself split at 4 x design working pressure. A number of vessels of this last design had been in service and no failures had occured.

No doubt experience with "Wickel" vessels, where the studs for the covers had to be screwed into the wound layers, provided the background for the last development in stiffening rings for solid-wall vessels.

To comply with German legal requirements the Test pressure for all vessels is 1.3 x the maximum working pressure. Cold vessels are designed with a working stress of at least $\frac{1}{1.6}$ x the elastic limit. In the case of hot-walled vessels, the working stress is set at $\frac{1}{1.6}$ x the creep limit for the steel at 300°C for solid walls and at $\frac{1}{1.6}$ x the creep limit at 350°C for "Wickel" vessels. For both types of vessel, allowances are made for the process in which the vessel is to be used, e.g. for well-established processes the factor of $\frac{1}{1.6}$ is adhered to, but for processes still undergoing development a ratio of $\frac{1}{1.7}$ to $\frac{1}{2.0}$ may be used.

The maximum ingot which can be cast by Krupps or other Forgemasters has a weight of 270 Tonnes and the largest forge is rated at 15,000 Tonnes. The largest solid wall vessel obtainable from this equipment is the 1000 mm. bore, 18 M long, 700 ats. converter, which weighs 110 Tonnes. Very few vessels had been lost on account of casting and forging faults; faults were ground out locally and extra metal left on the outside of the vessel or, if necessary, stiffening rings shrunk on.

The practice of grinding out local faults had been applied to the removal of marks on forgings caused by bomb splinters.

XIII. HYDROGEN-RESISTANT STEELS, ETC.

Ob. Ing. Koch and Dr. Class were interrogated on the 28th May regarding the development of hydrogen-resistant steels and their experience with them during the war. The steel in most widespread use was known as N.10, and its analysis given as 3.0 - 3.6% Cr, $\not>$0.5% Mo, $\not>$0.3% W, $\not>$ 0.75% V, 0.18 - 0.22%C; this is identical with the analysis quoted at Leuna. 520°C was given as the maximum metal temperature, and when this steel was used in preheaters at 700 ats, flue gas temperatures were restricted to 560°C maximum. N.10 tubing had an O.D./I.D. ratio of 1.7 to 1.8, which at 700 ats, gives a stress of 11.3 tons/sq.in. or 8.2 tons/sq.in. according as to whether the stress calculation is based on the elastic or plastic theory.

On account of failures of N.10 in service, the method of testing steels for hydrogen resistance had been changed during the war. The original testing period of 200 hrs, had been found too short and tensile testing of test pieces had not given satisfactory results. It was considered that the normal methods were not satisfactory for the testing of material to be used so near its limits and that test conditions should approach more nearly the actual plant conditions. The life-testing of tubes under working pressure and temperature had therefore been developed, the tubes themselves being scaled-down versions of plant tubes. In this way it was hoped to obtain results which would be of more direct applicability.

N.10 tubing was delivered in lengths of 3-4 m. when in the rolled form and 4-5 m. lengths when in the form of bored-out bars. The latter type had been favoured because with such thick-walled tubes the cost was very little greater than that for rolled tubes and there was no risk of trouble from the small faults that were always present in the bores of rolled tubes. The tubing was heat-treated according to a method developed at Leuna. After heating to 1050°C the steel has a Brinell hardness of at least 350, which falls to 250-280 on annealing.

Great difficulty had been experienced in heat-treating forged pieces of the alloy and the use of N.10 for forgings had been abandoned.

It was disclosed that V2A was in use at Welheim for 700 ats preheaters and that no running difficulties had been experienced. It was stated that I.G. would have used V2A for 700 ats. preheaters if nickel had been available, since the creep strength of V2A was superior to that of N.10 at high temperatures.

Formerly, V2A sheets had been used for lining catalyst baskets in order to guard against H_2 attack and sulphur attack. When supplies became difficult, 15 mm. thick ordinary steel shells were used with an internal plating of V2A only 1 mm. thick; at the same time, this gave a stronger basket which was not so likely to fail during a rapid blow-down.

Because of the shortage of chromium and molybdenum, manganese had been used instead in the case of flange steels, and there had been considerable difficulty in achieving the required tensile properties without getting a steel which was too brittle and susceptible to cracking. Because of its reduced ductility, the substitute steel was used only up to 350°C. The steel had the following analysis:- 1.1%-1.4% Mn., 1.1-1.4% Si., and 0.4% C; after water quenching, the tensile strength was 50-60 tons/sq.in.

In connection with the failure of injector pump blocks, it was considered that the trouble was due to the presence of occluded hydrogen and other impurities left in the steel during casting which did not manifest themselves at pressures of 300 ats. but which became important at 700 ats. The reason for the more numerous failures on the three-throw pumps arose from the fact that they underwent much more frequent stress reversals than the I.G. paste pumps.

APPENDIX A.

C.I.O.S. OIL TEAM VISITING LUDWIGSHAFEN/OPPAU 25-31/3/45

Leader:	Mr.P.K.Kuhne	U.S. Petroleum Administration for War.
Deputy Leader:	Lt.Col.R.Holroyd	British Ministry of Fuel and Power.

Dr.E.L. Baldeschwieler Mr.E.Cotton Mr.L.P. Evans Dr.W.F. Faragher Dr.V.Haensal	U.S. Petroleum Administration for War
Dr.L.L. Hirst Dr.G. Von Elbe	U.S. Department of the Interior, Bureau of Mines.
Dr.E.B. Peck	U.S. Foreign Economic Administration.
Lt.Col.D.Morton Lt.Col.H.C.Tett Major C.Cockram Major F.A. Williams Capt.C.M.Cawley Capt.T.A.G.Plant	British Ministry of Fuel and Power.

Later Visit (July)

Dr.W.A.Horne	U.S. Petroleum Administration for War.

APPENDIX B(1)

HEAT EXCHANGERS USED IN KW PLANTS AT OPPAU & HEYDEBRECK

	OPPAU		HEYDEBRECK
No. Tubes	688		400
	Upper Portion	Lower Portion	
Tube Material	Furodit 10	ST-00	FF-18
Tube Length, mm.	2625	3275	4850
" O.D. mm.	24	25	22
" I.D. mm.	21	20	18
SHELL			
Material	Furodit 8		Sicromal 3
Length (overall) mm.	7400		5900
I.D. mm.	1184		1300
Thickness mm.	8		8
No. Baffles	9		12
REF. DRAWING No.	F.10268-1 *		4760

* Photograph of tube bundle during shutdown in March 1941 also available, in documents.

APPENDIX B(2)

Calculations on KW Plant, Heydebreck. 9.3.42

For 3,500 M^3/hour of CH_4; for preheat of gases to 650°C and reactor outlet of 850°C

Analysis

	Input		After Reaction	Water Gas Equilib. (1)	Cracked Gas Parts	Cracked Gas %
CO_2	-	-	-	+ 0.225	0.225	7.0
	-	0.487 O_2	-	-	-	-
CO	-	-	0.994	- 0.225	0.769	23.8
H_2	-	-	2.008	+ 0.225	2.233	69.0
CH_4	1.000	-	0.006	-	0.006	0.2
Dry Gas	1.000	-	-	-	3.233	100.0
M^3 H_2O	1.000	-0.020	0.980	- 0.225	0.755	
gms H_2O	735				556	

(1) Water gas equilibrium constant at 850°C K = 1.16

For the above conditions the heat balance in the reactor is estimated as follows.

(a) Oxygen requirements per cu.m. CH_4 are 0.487 cu.m.

(b) Heat balance

Heat generated

1) $CH_4 + 1/2\ O_2 = CO + 2\ H_2$

Δ H at 650° = 269 WE/NM^3

269 x 0.974 = 262

2) $CO + H_2O = CO_2 + H_2$

Δ H at 650° = 337 WE/NM^3

337 x 0.225 = 76

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Heat consumed

3) $CH_4 + H_2O = CO + 3\ H_2$

Δ H at 650° = -2689 WE/NM^3

2689 x 0.02 = 54

4) Heat the cracked gases from 650-850°

$\Delta T \times C_p$ = 200 x 1.322 = 264

5) Heat losses (WE/M^3 CH_4) 20

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Heat Exchanger

Input

Sensible heat of cracked gas 0-850° in WE/M^3 CH_4 1,068

850 x 1.257 (2)

Latent heat of water in gas 0.556 x 595 331

1,399 WE/M^3 CH_4

Output

Sensible heat of feed gases (0-650°)(3)

650 x 1.098 } 1150

Latent heat of water in gas }

0.735 x 595 }

Less heat in O_2 at 15°C

-0.487 x 15 x 0.917 x 0.311 -2

Less heat in steam added

206 gms H_2O from saturator 156 WE

-156

529 gms steam at 1.5 ats (111°)

.529 x 643.8 340 WE

-340

652 652 WE/M^3 CH_4

Heat left in cracked gas after heat exchanger

1399-652 = 747 WE/M^3 CH_4

and the indicated outlet temperature is

$(747-331) : 1.322 = \frac{416}{1.32} = 315°$

AVERAGE SPECIFIC HEATS

(2) Cracked Gases

	mols.	Sp.heat (0-850)	
CO_2	0.225	x 0.503	= 0.114
CH_4	0.006	x 0.746	= 0.005
H_2O	0.755	x 0.390	= 0.294
Diatomic gases	3.002	x 0.319	= 0.958
			1.371

1.371 x 0.917 = 1.257

Note (3)

Feed Gases

CH_4	1.000 x 0.661	= 0.661
H_2O	1.000 x 0.382	= 0.382
O_2	0.487 x 0.316	= 0.154
		1.197

1.197 x 0.917 = 1.098

APPENDIX C

LARGE SCALE PRODUCTION OF SYNTHETIC FERTILIZERS.

In our letter to Military Government, dated April 15th, we gave a survey of the minimum production capacities for synthetic fertilizers at our Oppau plant and described in particular the requirements of coke and coal for this limited production volume. On special request we have now made an investigation of conditions for maximum output of final products, and we give the results of this investigation in the table attached to this report.

The output of fertilizers depends on the repair-work at those installations that have suffered most damage by bombing. While the gas and ammonia plants are in good working conditions, there is some damage at the coal transport system for the boiler houses, and this repair will require about 6 months. Although the production of the ammonia plant might be as large as 500 tons/day per September 1st, it is limited to 170 tons/day for this decreased efficiency of the coal conveyance. After December 1st, the state of the different manufacturing plants governs the real output of final products as given in the columns 9-16 of the table. From column 16 and the note to it results a maximum capacity of about 500 tons/day of nitrogen or a production of about 180,000 tons/year of nitrogen, out of which more than 900,000 tons of marketable fertilizers can be manufactured.

As we had already occasion to point out we always had a surplus production of ammonia which we despatched for manufacturing into fertilizers to our plants at Hoechst, Wolfen and Bitterfeld. The quantity available for despatch is given in column 17 of the table. The manufacturing capacity at Hoechst being of the order of 200 tons/day, there will be no demands for transportation to the plants at Wolfen and Bitterfeld before January 1946, the only condition being a regular communication between Ludwigshafen and Frankfurt/M - Hoechst.

The requirements for coke and Ferngas for the synthesis, and coal and lignite for the power plants are given in the column 5-8. We are prepared to receive Ferngas up to 400,000 cbm/day with a corresponding decrease in the demand of coke.

In column 3 we have mentioned a production of 50 tons/day of methanol as it was suggested to Military Government at Ludwigshafen in our memorandum dated April 20th, 1945. This production of methanol and an additional one of butyl may be raised with the progress of repair-work at the coal conveyance of our plant; the output of nitrogen is not afflicted by the simultaneous production of these chemicals.

The maximum capacity of the primary plants for the four main products will be :-

nitrogen	–	750 tons/day
methanol	–	120 " "
Butyl	–	400 " "
hydrogen	–	192,000 cbm/day

and will be obtained during the first months of 1946.

Beyond the demand for coke, Ferngas, coal and lignite, we shall require limestone for the production of Kalkammonsalpeter and gypsum for the production of ammonium sulphate. A lime of good qualities for our purposes can be got at Gundersheim/Neckar. Gypsum was supplied till now from Niedersachswerfen/Harz: as long as there are transport difficulties we might use a gypsum that can be taken from a quarry at Obrigheim/Neckar and belongs to the Portland Zementwerke at Heidelberg. The quarries at Gundersheim and Obrigheim are not far from each other and the distance from Ludwigshafen is approximately 50 miles.

The total transport volume for these auxiliary raw materials will be :-

per	gypsum tons/day	lime tons/day	total tons/day
1.6.45	–	80	80
1.9.45	90	130	220
1.12.45	250	310	560
1.5.46	420	325	745
1.5.47	420	325	745

There is an ample stock of lime available at Oppau to run production of Kalkammonsalpeter for at least 2 months before new supply from Gundersheim will be necessary.

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TIME-TABLE FOR RE-ESTABLISHMENT OF NITROGEN PLANT AT

Date	Production capacities of primary plants			Fuel requirements			
	nitrogen	methanol	hydrogen	coke	Ferngas	coal	lignite briquettes
1	2	3	4	5	6	7	8
	tons/day	tons/day	cbm/day	tons/day	cbm/day	tons/day	tons/day
at once	50	50	48,000	200	100,000	400	-
1.6.45.	170(1)	50	120,000	500	100,000	800	100
1.9.45.	170	50	120,000	500	100,000	800	100
1.12.45.	500	50	192,000	1,100	100,000	1,500	200
1.5.46.	750	50	192,000	1,600	100,000	1,800	200
1.5.47.	750	50	192,000	1,600	100,000	1,800	200

(1) output limited by damage at internal coal transport system. Repair work requires 5-6 months.

I.G. LUDWIGSHAFEN-OPPAU.

Real output of marketable products								Spare nitrogen for dispatch
ammonium sulphate	ammonium chloride	ammonium bicarb.	urea	Kalkammon-salpeter	sodium nitrate	calcium nitrate	total	
9	10	11	12	13	14	15	16	17
tons/ day N	tons/ day N	tons/ day N	tons/ day N	tons/ day N	tons/ day N	tons/ day N	tons/ day N	tons/ day N
-	-	5	-	45	-	-	50	-
-	4	5	19	45	-	-	73	97
33	4	7	31	68	3	-	146	24
50	4	9	32	168	7	-	270 (2)	230
84	10	15	46	180	12	29	376	374
84	10	15	46	180	16	76	427 (3)	323

(2) after repair of coal transport system bottle-neck at the final production plants.

(3) after full repair of all damage and further completion of Kalkammonsalpeter plant the whole capacity may be raised to 500 tons/day N.

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