



UNIVERSITÀ DEGLI STUDI DI PISA
FACOLTÀ DI INGEGNERIA

8. Sistemi Termici Operatori

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DIPARTIMENTO DI ENERGETICA

Anno Accademico 2005-06

COMPRESSORI

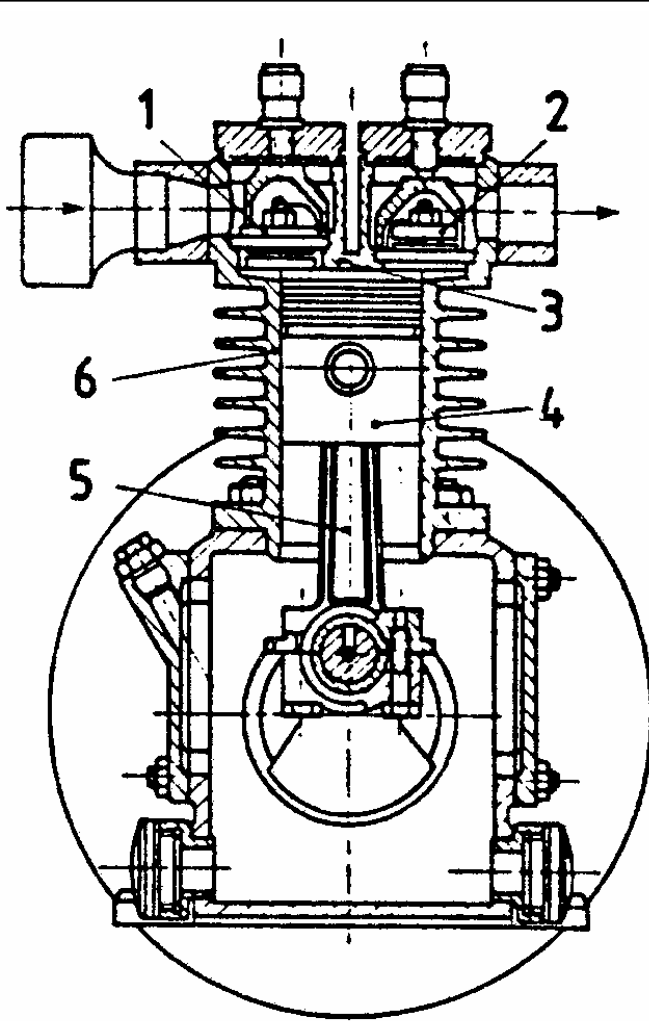


Fig. 1 - Compressore alternativo a pistone monocilindrico raffreddato ad aria

- 1 valvola di aspirazione
- 2 valvola di mandata
- 3 testata
- 4 pistone
- 5 biella
- 6 cilindro alettato

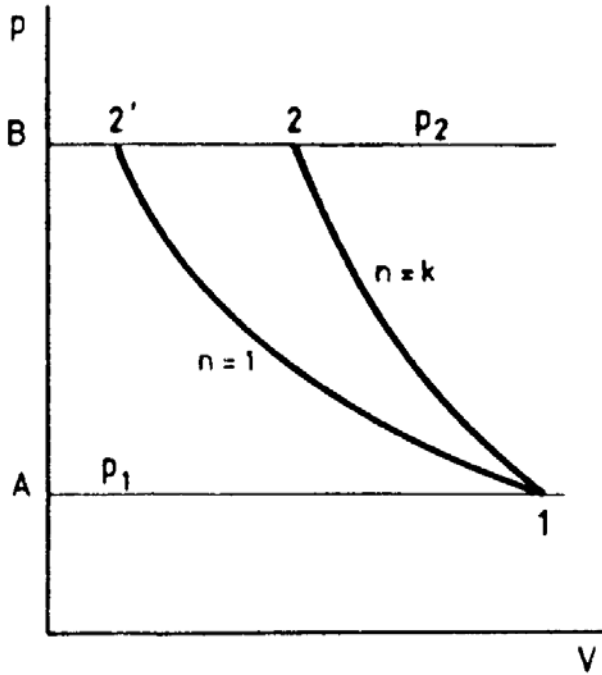


Fig. 2 - Compressione isoterma (1-2') e compressione adiabatica (1-2)

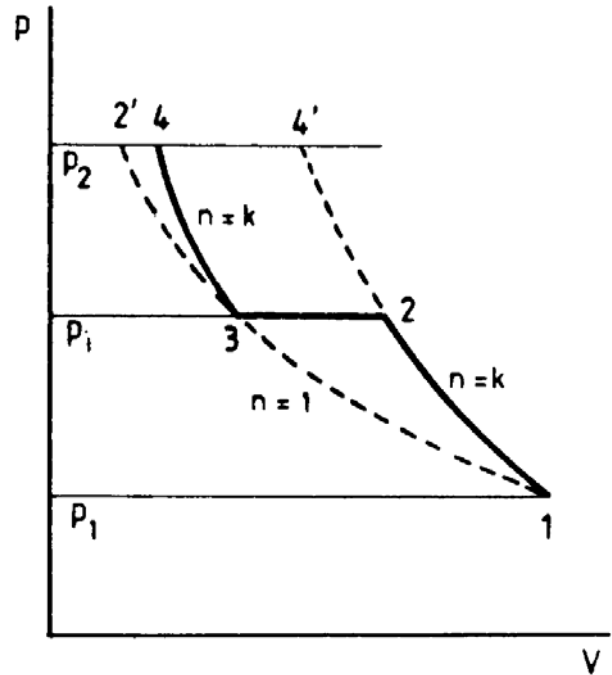


Fig. 3 - Compressione isoterma (1-3-2') e compressione adiabatica in due stadi con interrefrigerazione (1-2-3-4)

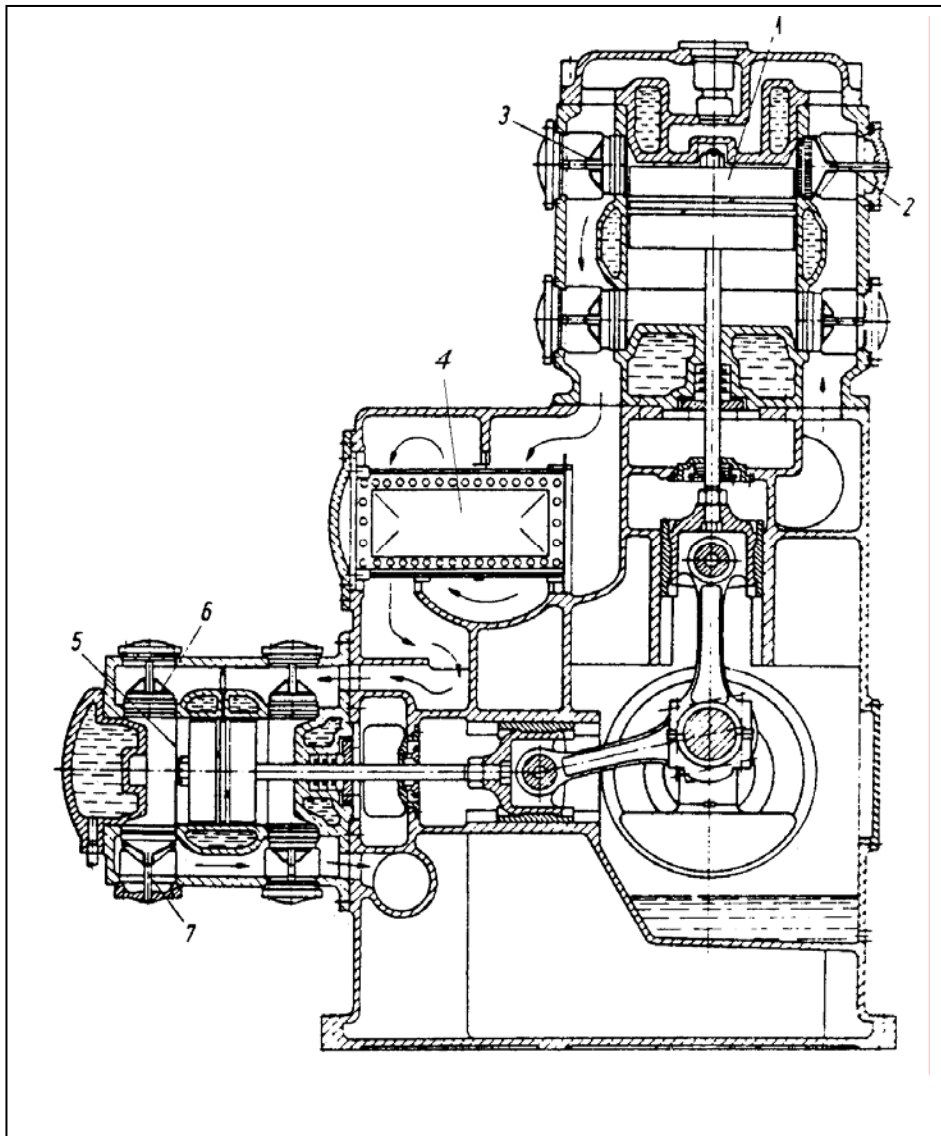


Fig. 4 - Compressore d'aria alternativo con due cilindri a *L* e refrigerazione intermedia

$Q=32 \text{ m}^3/\text{min}$; $P=200 \text{ kW}$; $\beta=10$

- 1 cilindro verticale
- 2 valvola di aspirazione
- 3 valvola di mandata
- 4 refrigeratore intermedio
- 5 cilindro orizzontale
- 6 valvola di aspirazione
- 7 valvola di mandata

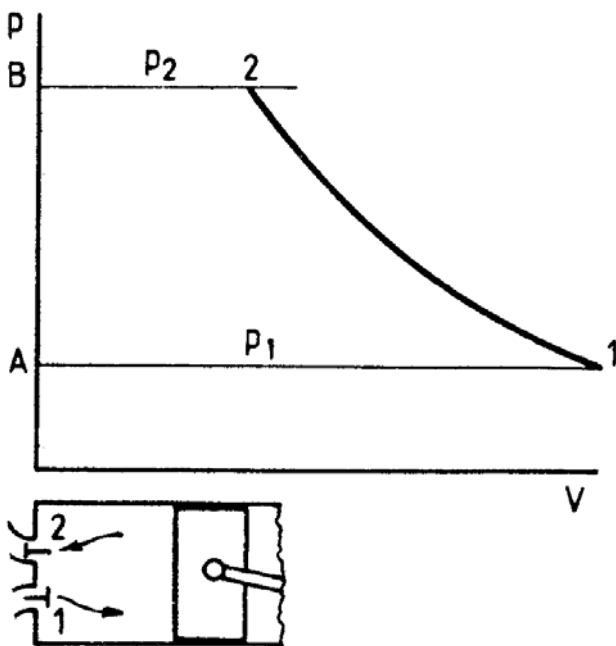


Fig. 5 - Diagramma di riferimento di un compressore alternativo senza spazio morto (1 valvola di aspirazione; 2 valvola di mandata)

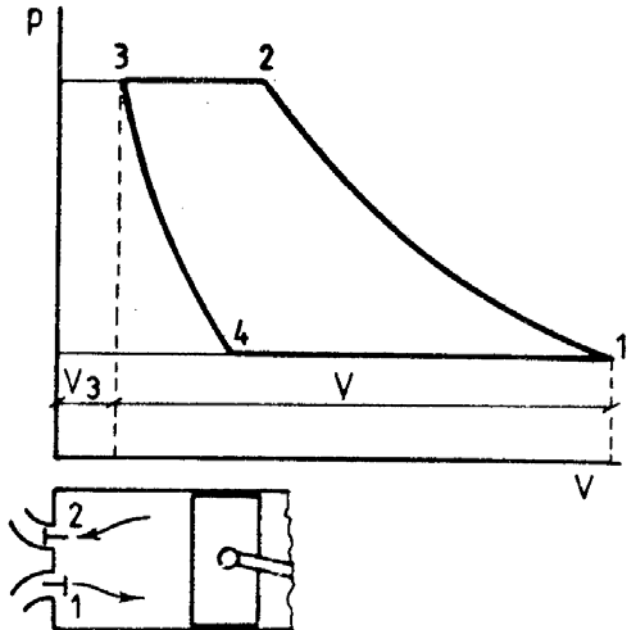


Fig. 6 - Diagramma di riferimento di un compressore alternativo con spazio morto (1 valvola di aspirazione; 2 valvola di mandata)

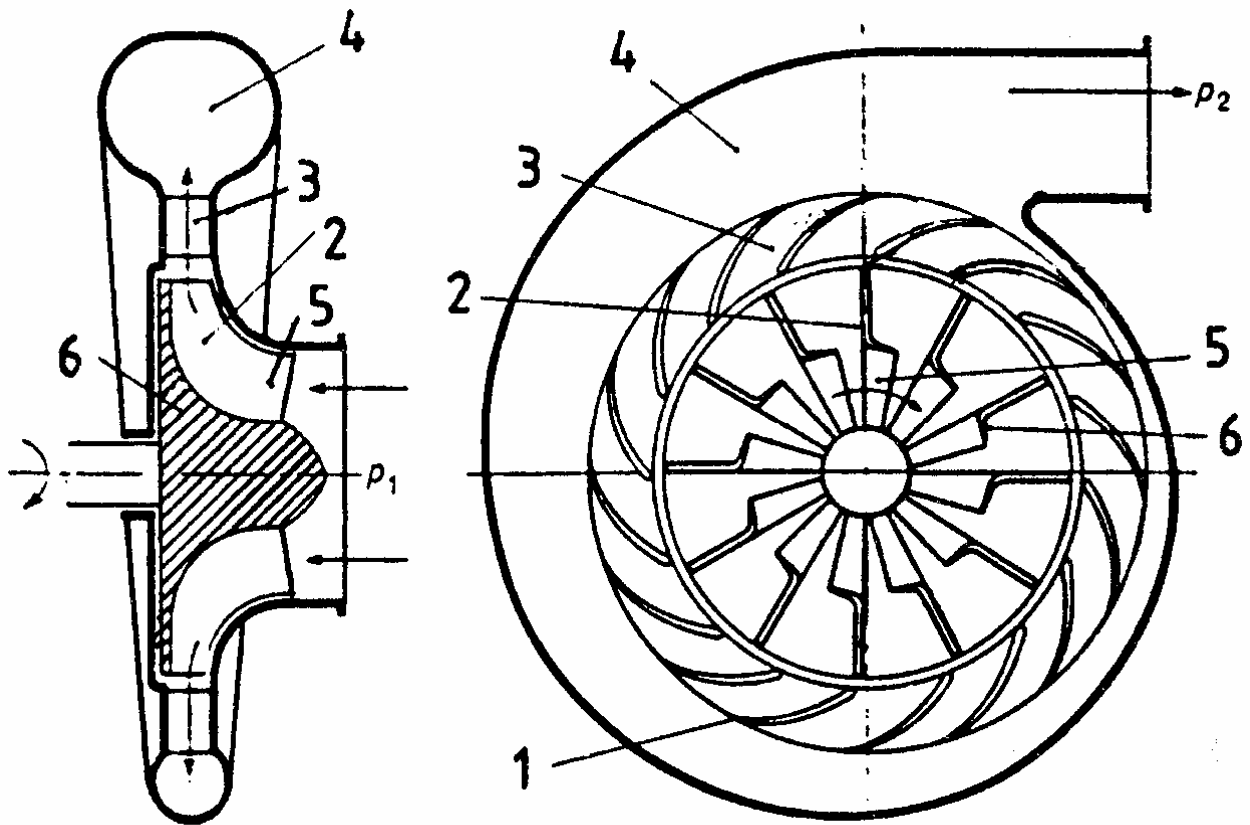


Fig. 7 - Compressore centrifugo

1 pale del diffusore; 2 pale della girante; 3 diffusore; 4 chiocciola di raccolta; 5 pregirante; 6 girante

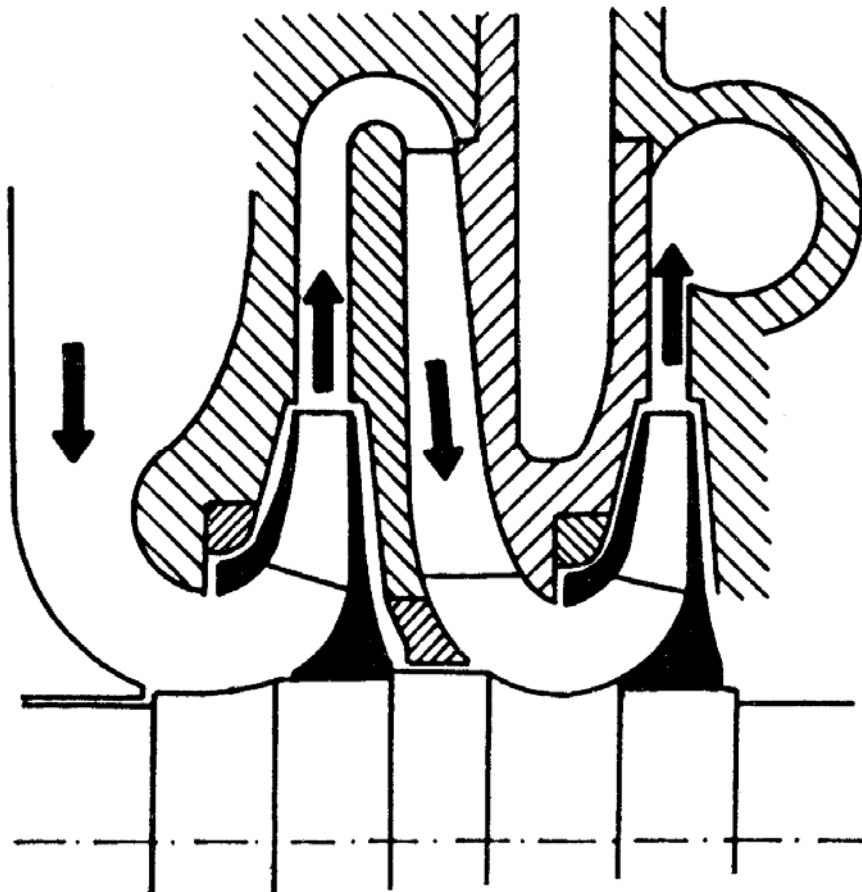


Fig. 8 - Canali di ritorno in un compressore centrifugo multistadio

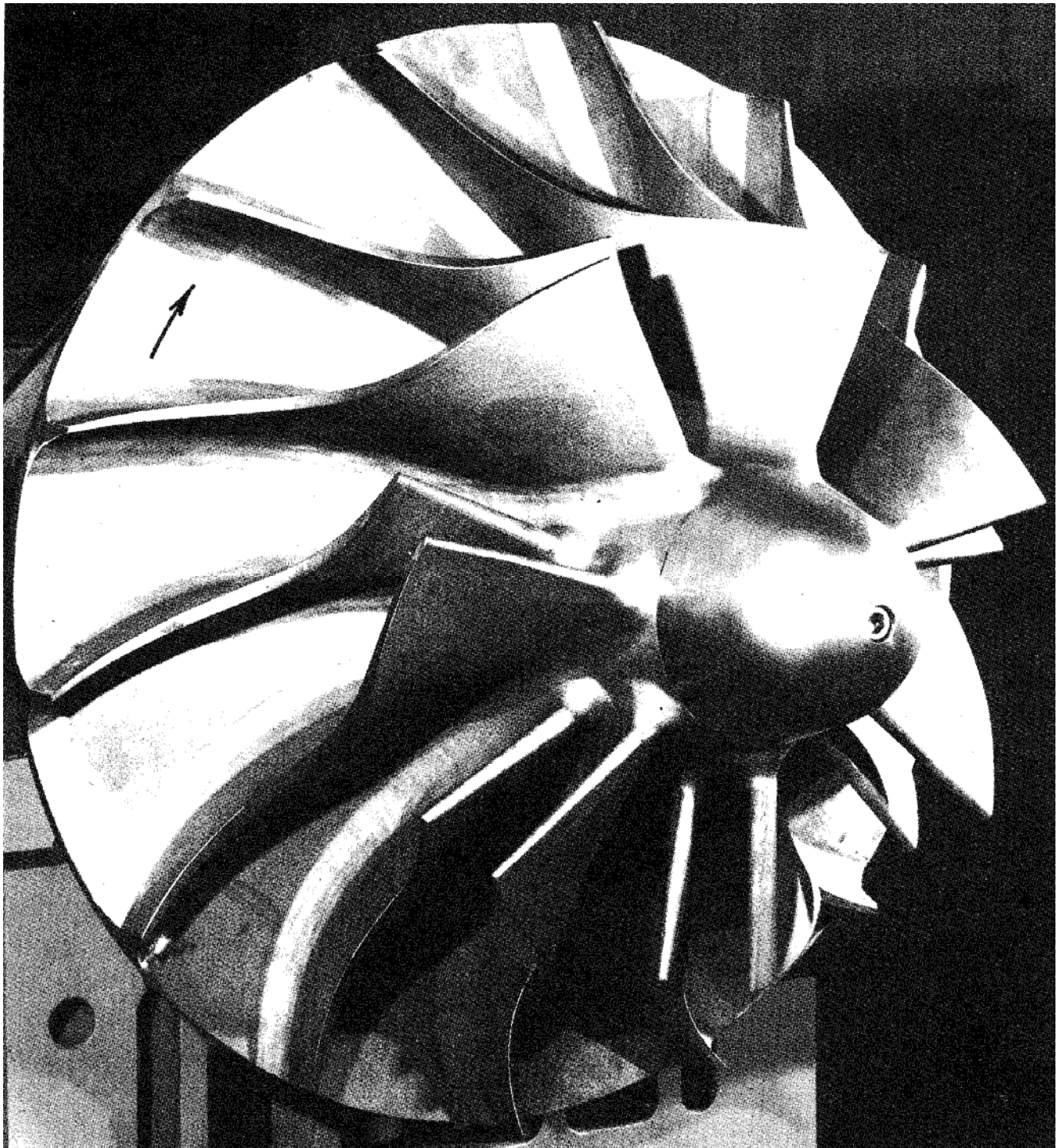


Fig. 9 - Girante di pompa centrifuga con pale rivolte all'indietro

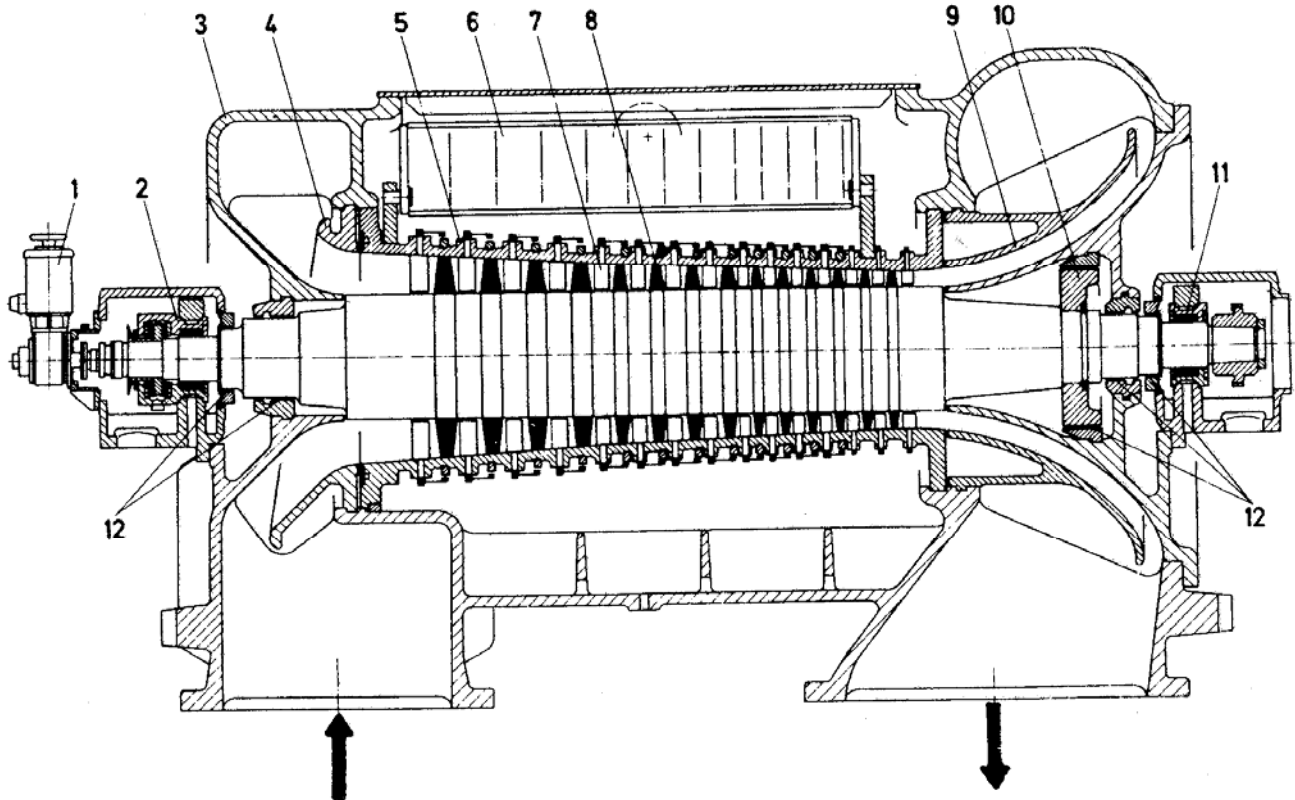


Fig. 10 - Sezione longitudinale di compressore assiale

3 carcassa esterna; 4 voluta di ingresso; 5 portapalette statoriche; 6 piastra per orientamento palette statoriche; 7 palette statoriche; 8 palette rotoriche; 9 diffusore di scarico

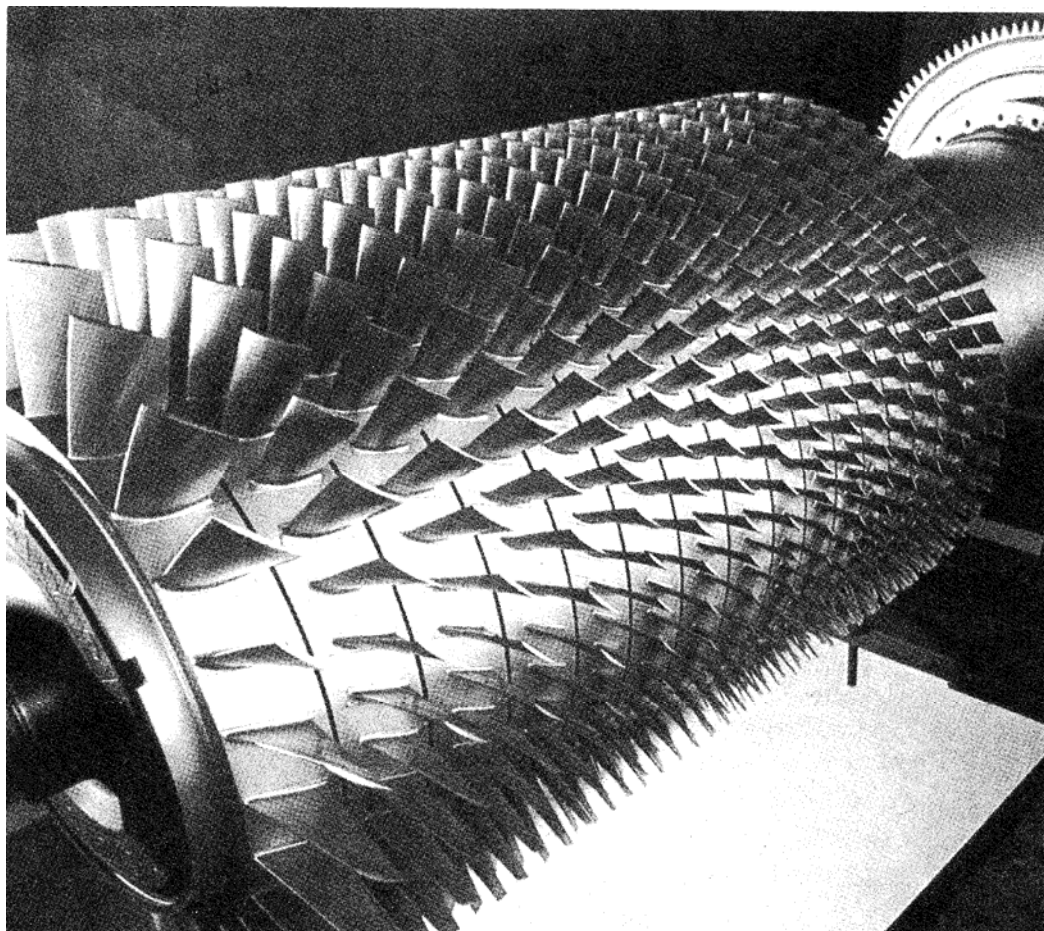


Fig. 11 - Rotore di compressore assiale

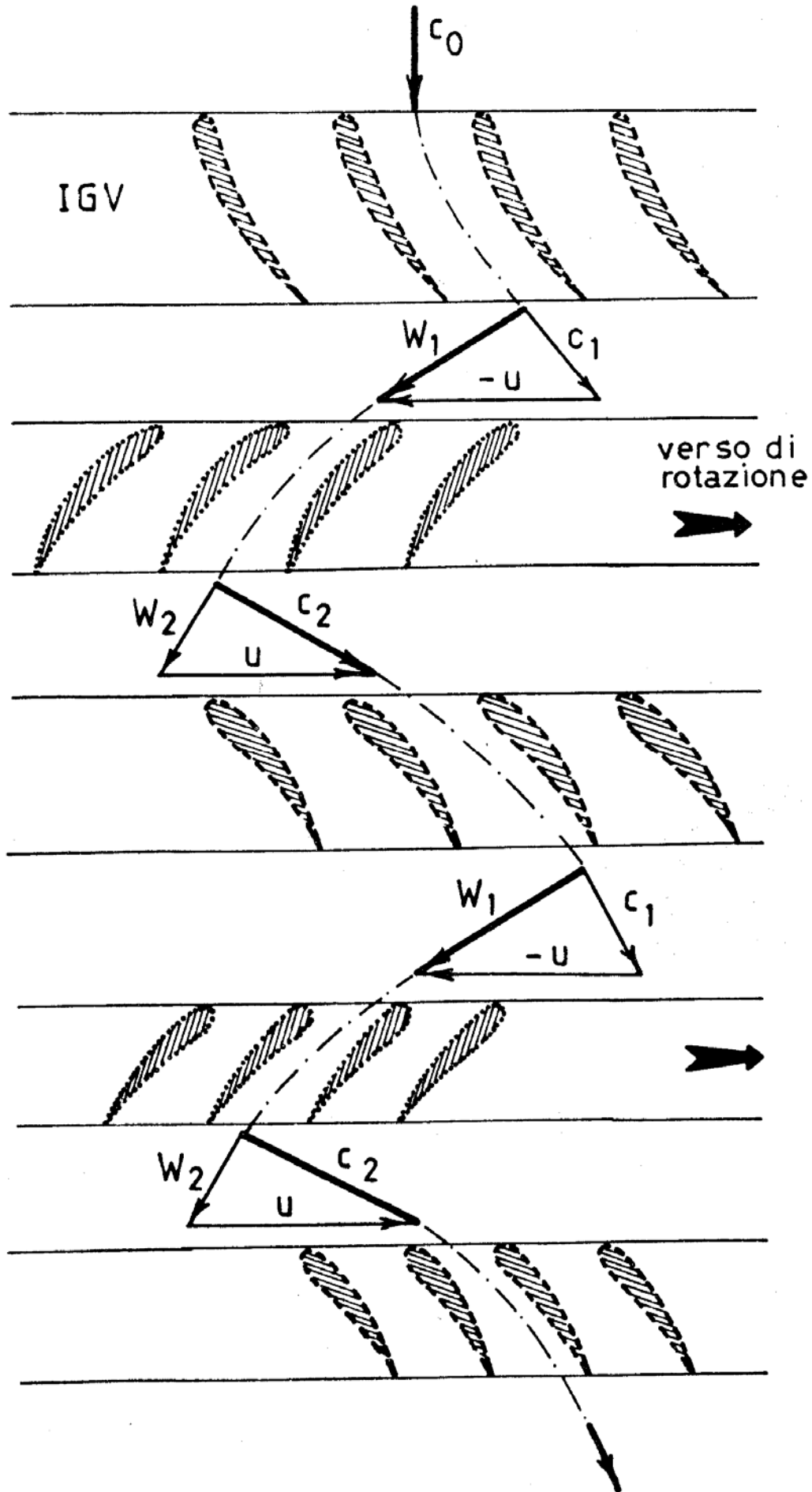


Fig. 12 - Triangoli delle velocità in ingresso ed in uscita relativi alla palettatura rotorica di un compressore assiale

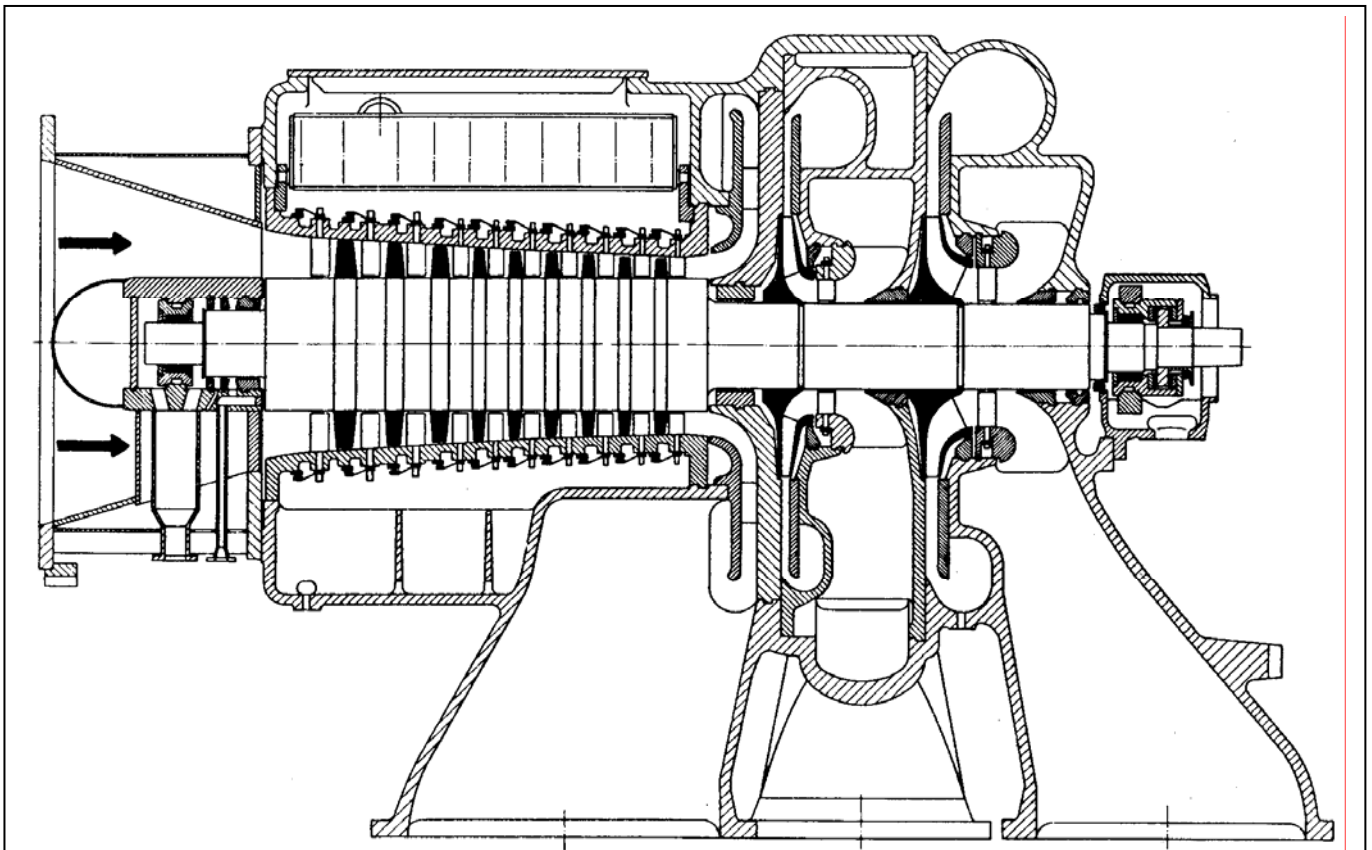


Fig. 13 - Sezione longitudinale di compressore misto assial-centrifugo

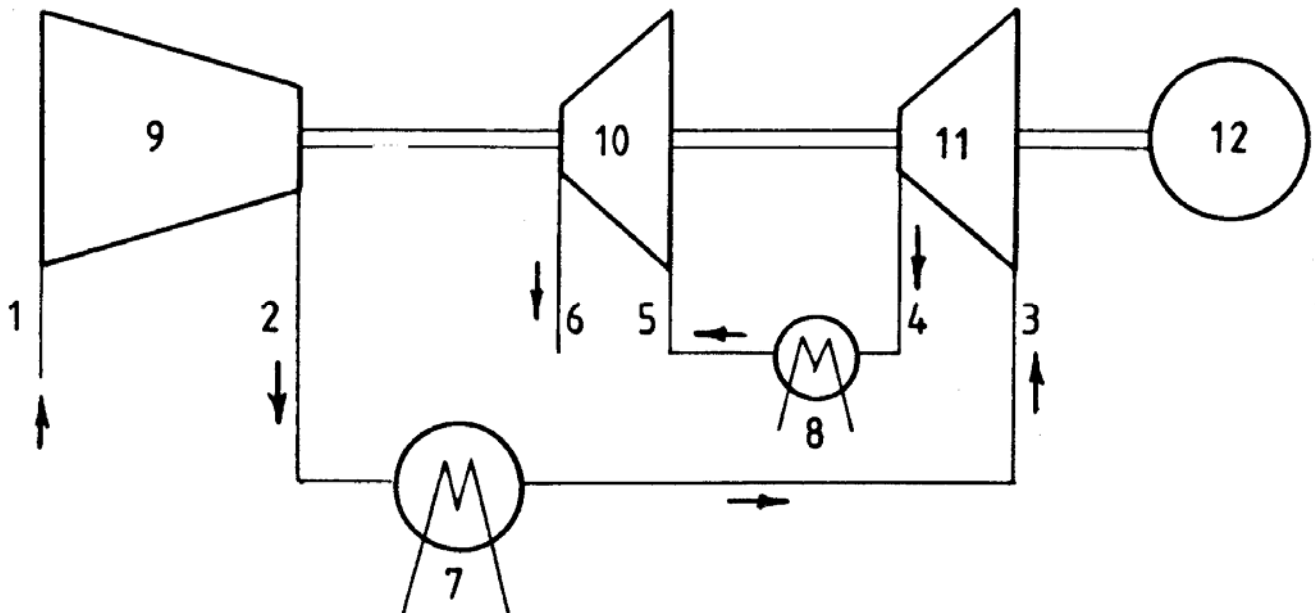


Fig. 14 - Schema del percorso del fluido nel compressore assial-centrifugo della figura precedente

1 ingresso assiale del fluido; 2 uscita dal corpo assiale verso il primo refrigeratore; 3 ingresso allo stadio centrifugo di bassa pressione; 4 uscita dallo stadio centrifugo di bassa pressione; 5 ingresso allo stadio centrifugo di alta pressione; 6 uscita dallo stadio centrifugo di alta pressione verso l'utilizzatore; 7 primo refrigeratore; 8 secondo refrigeratore; 9 corpo assiale; 10 stadio centrifugo di alta pressione; 11 stadio centrifugo di bassa pressione; 12 motore di azionamento

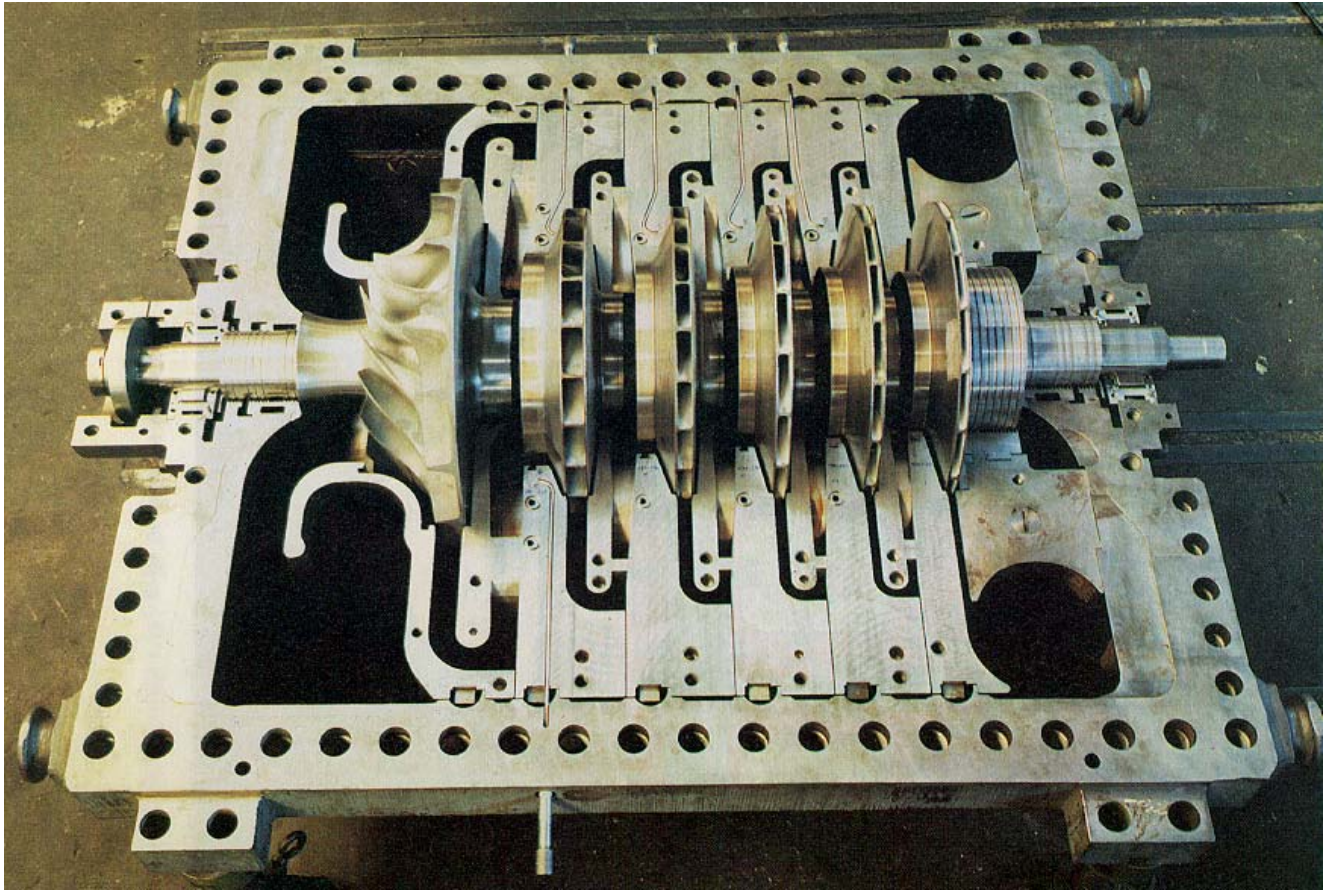


Fig. 15 - Compressore centrifugo con girante del primo stadio di tipo aperto

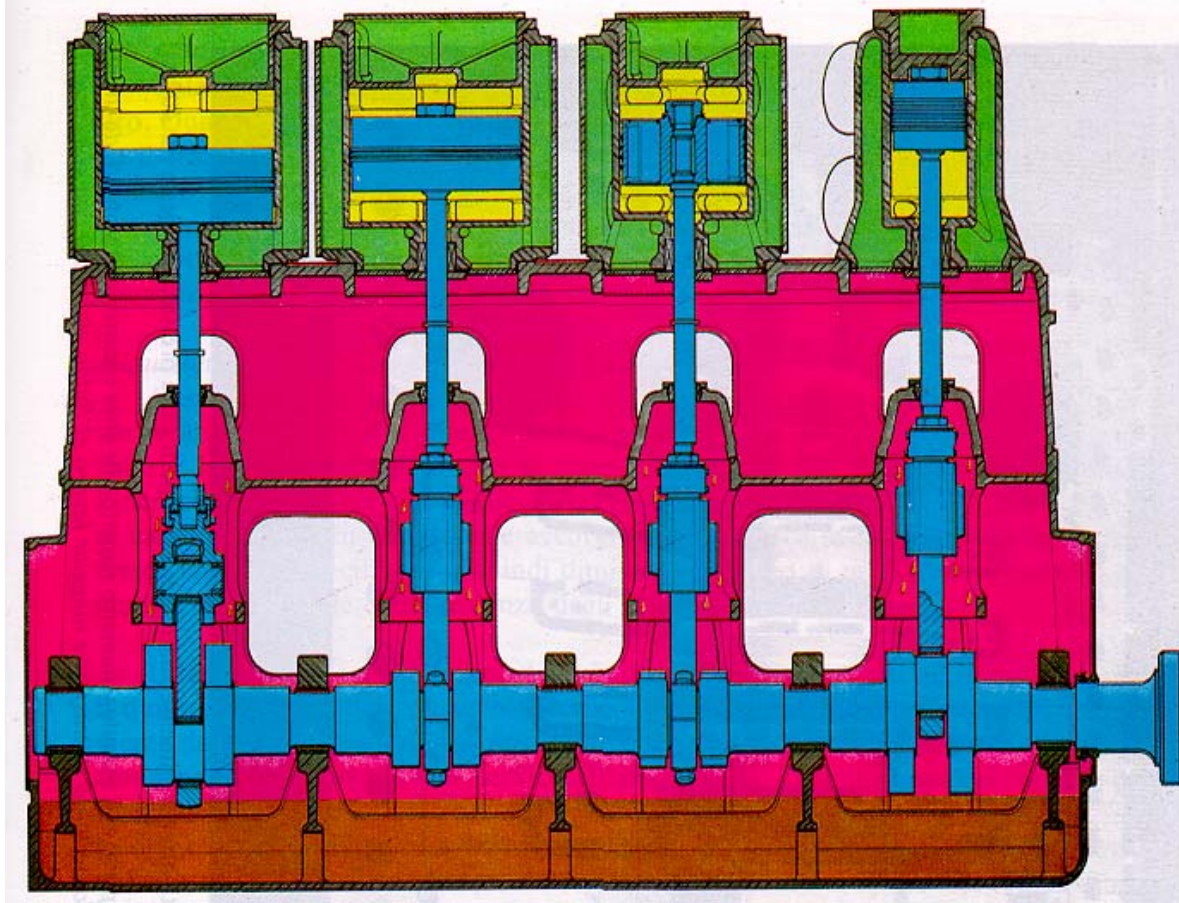


Fig. 16 - Compressore alternativo a quattro cilindri verticali

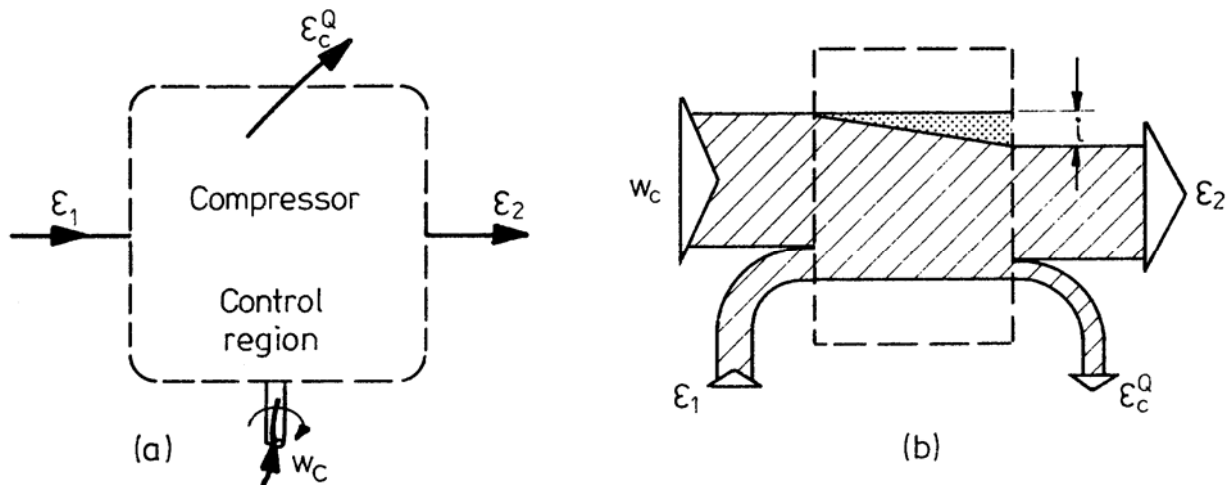


Fig. 17 - Processo di compressione: a) regione di controllo; b) diagramma di Grassmann

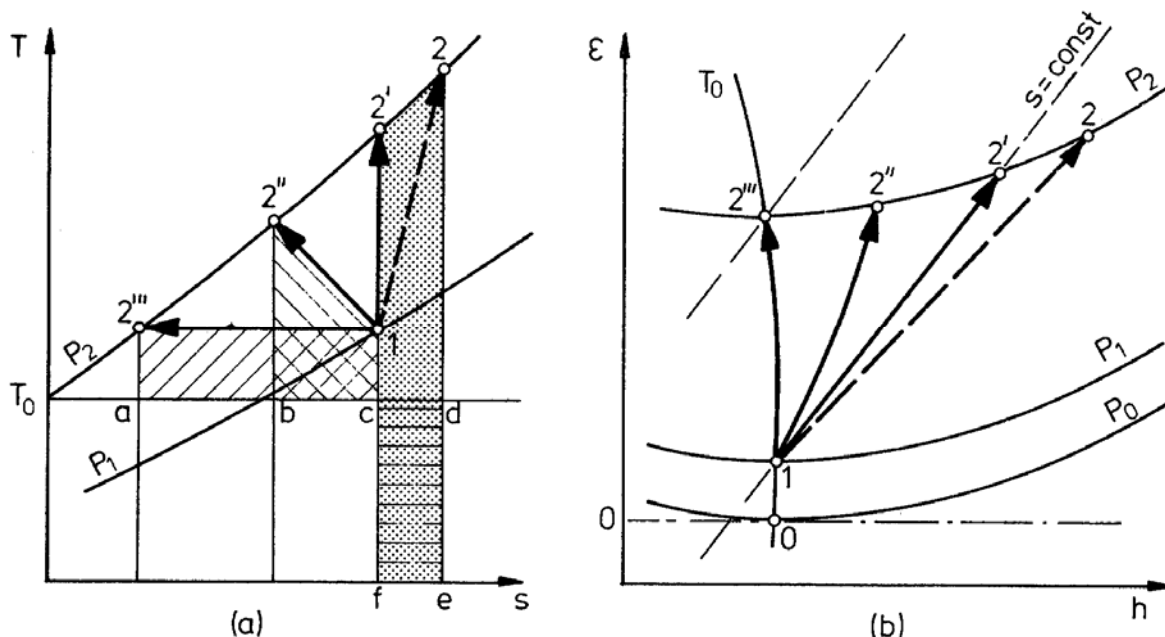


Fig. 18 - Trasformazioni di compressione: a) per $T_1 > T_0$ nel piano (T-s); b) per $T_1 = T_0$ nel piano (ϵ_{ph} -h)

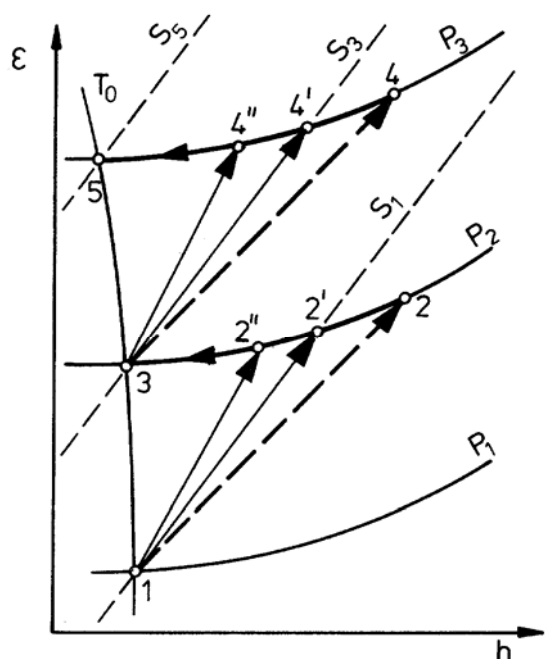


Fig. 19 - Compressioni in due stadi con refrigerazione intermedia per $T_1 = T_0$ nel piano (ϵ_{ph} -h)

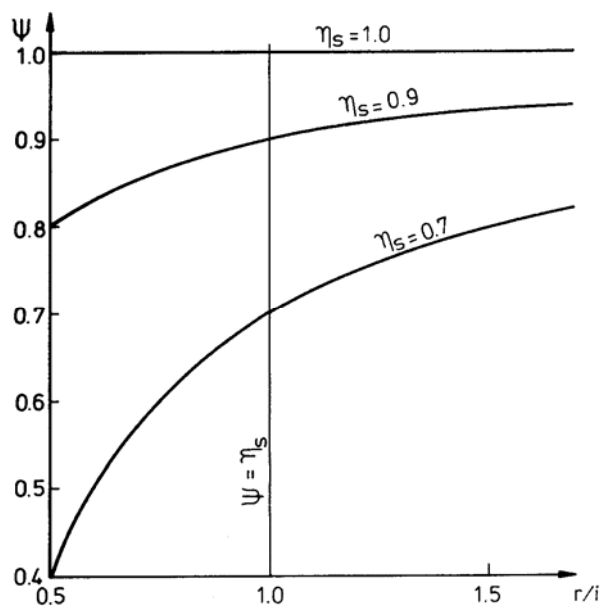


Fig. 20 - Compressori adiabatici: relazione tra rendimento exergetico e rendimento isoentropico

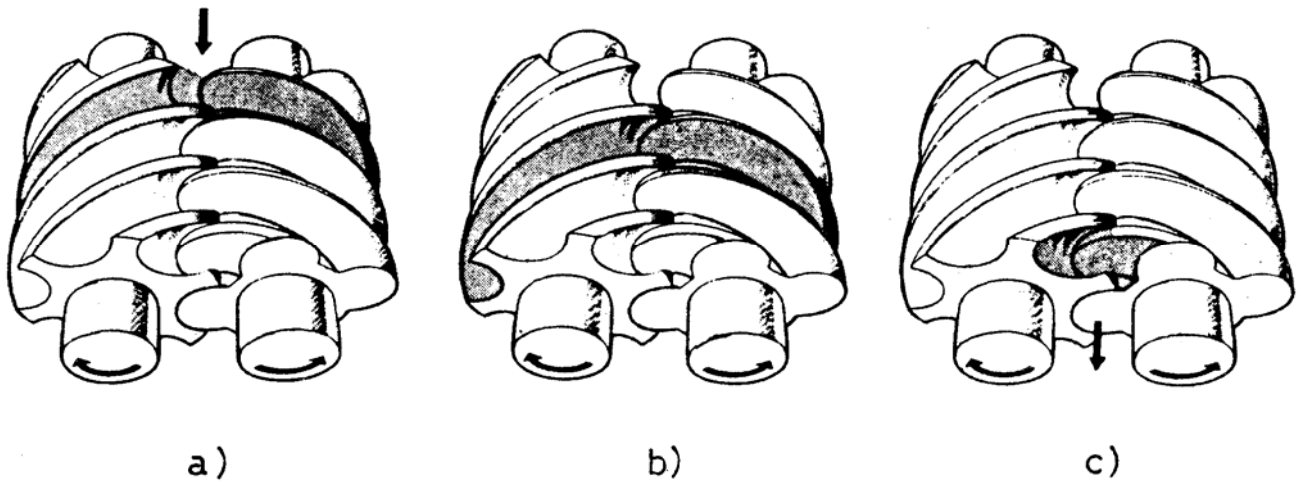


Fig. 21 - Compressore rotante a vite: a) aspirazione; b) compressione; c) scarico

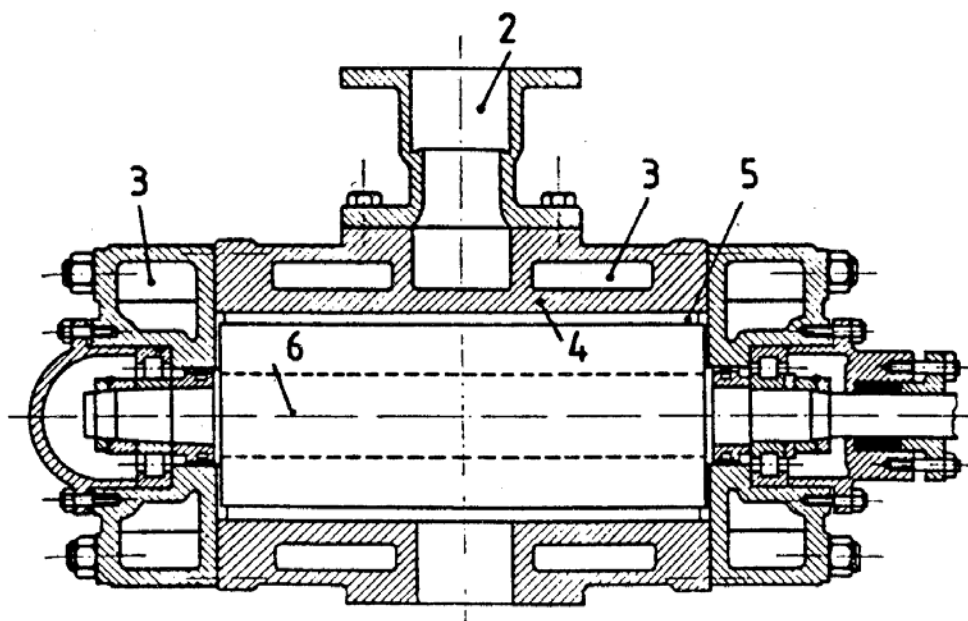
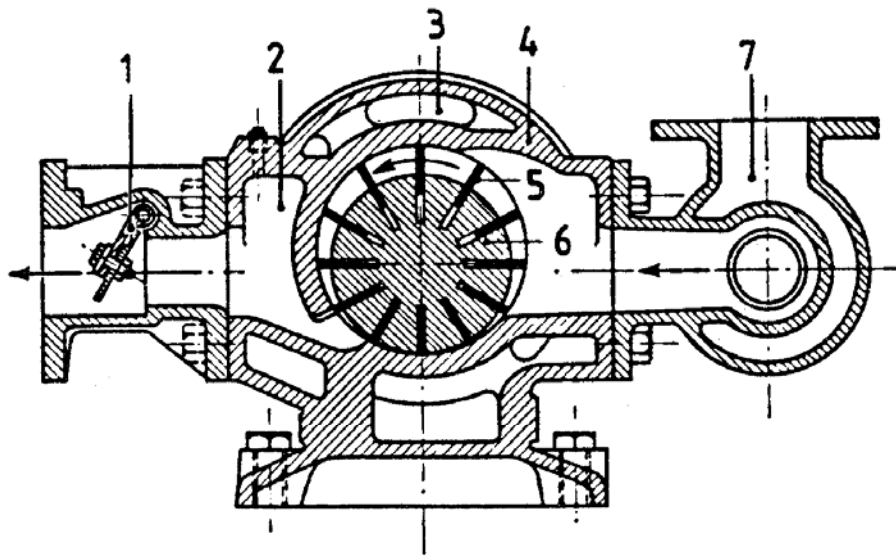


Fig. 22 - Compressore rotante a palette refrigerato ad acqua: 1 valvola di ritegno sulla mandata; 2 mandata; 3 camicia per l'acqua di refrigerazione; 4 carcassa o statore; 5 palette; 6 rotore; 7 aspirazione

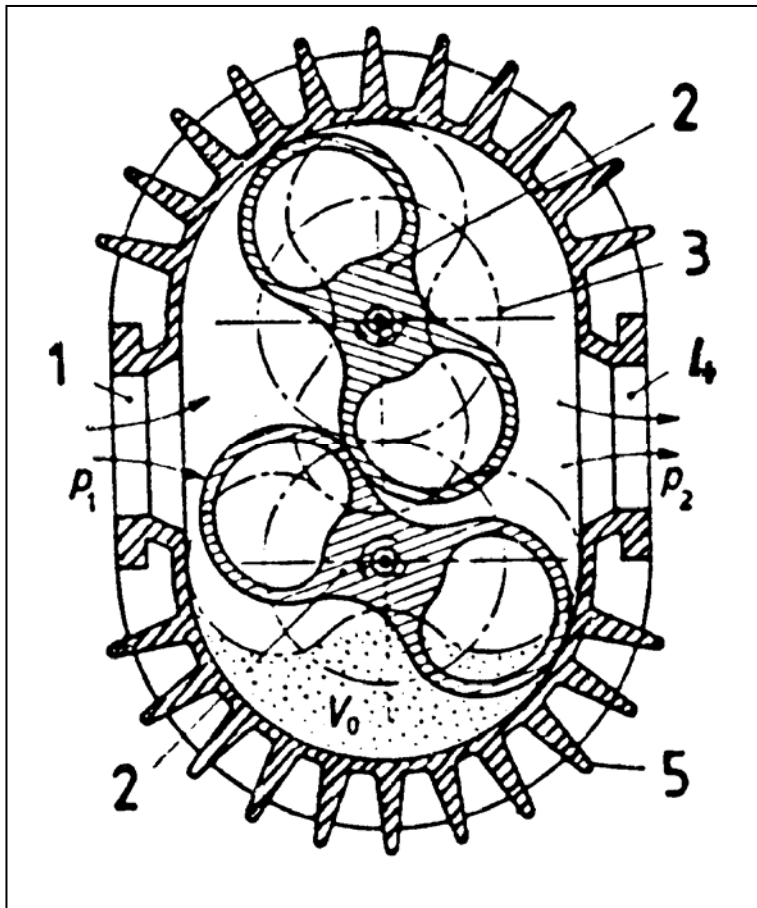


Fig. 23 - Compressore rotante a lobi refrigerato ad aria

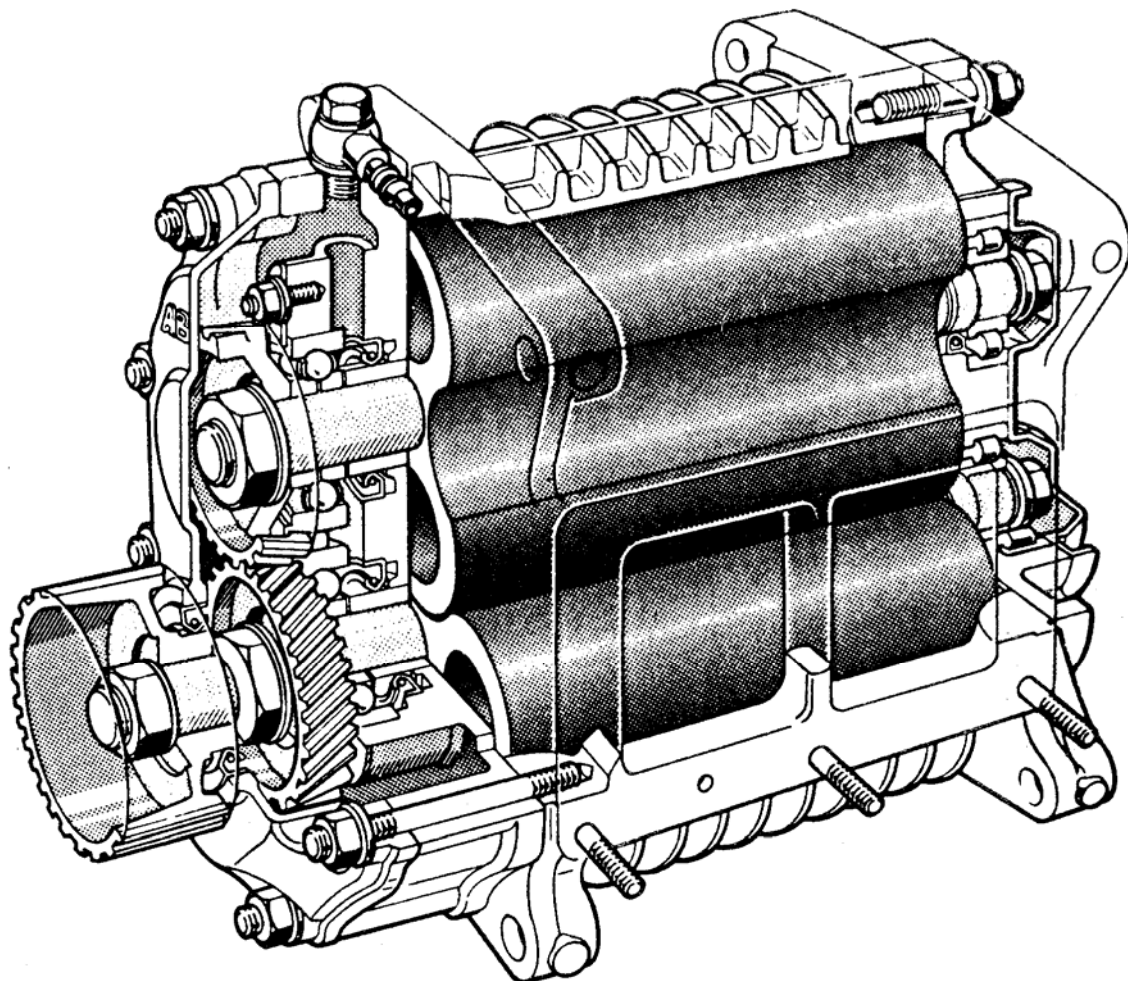
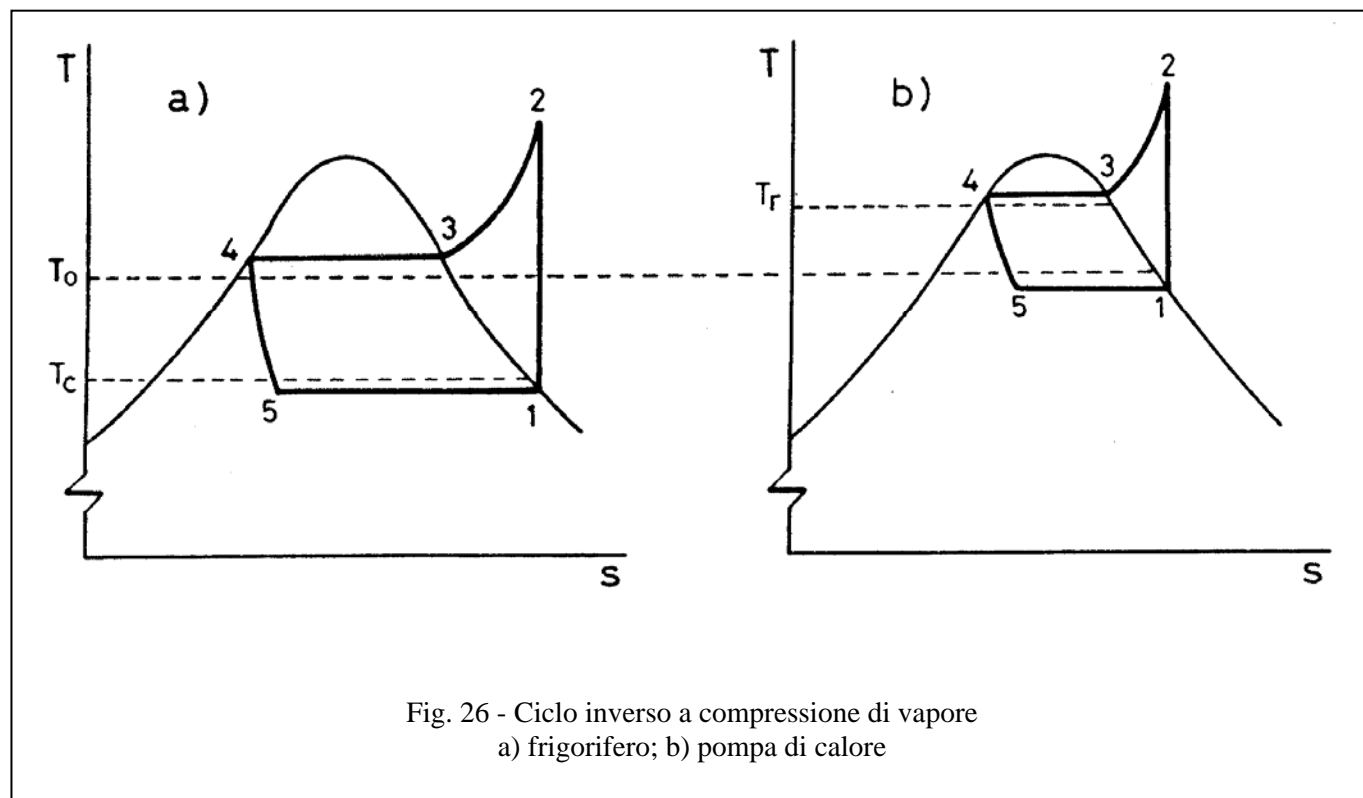
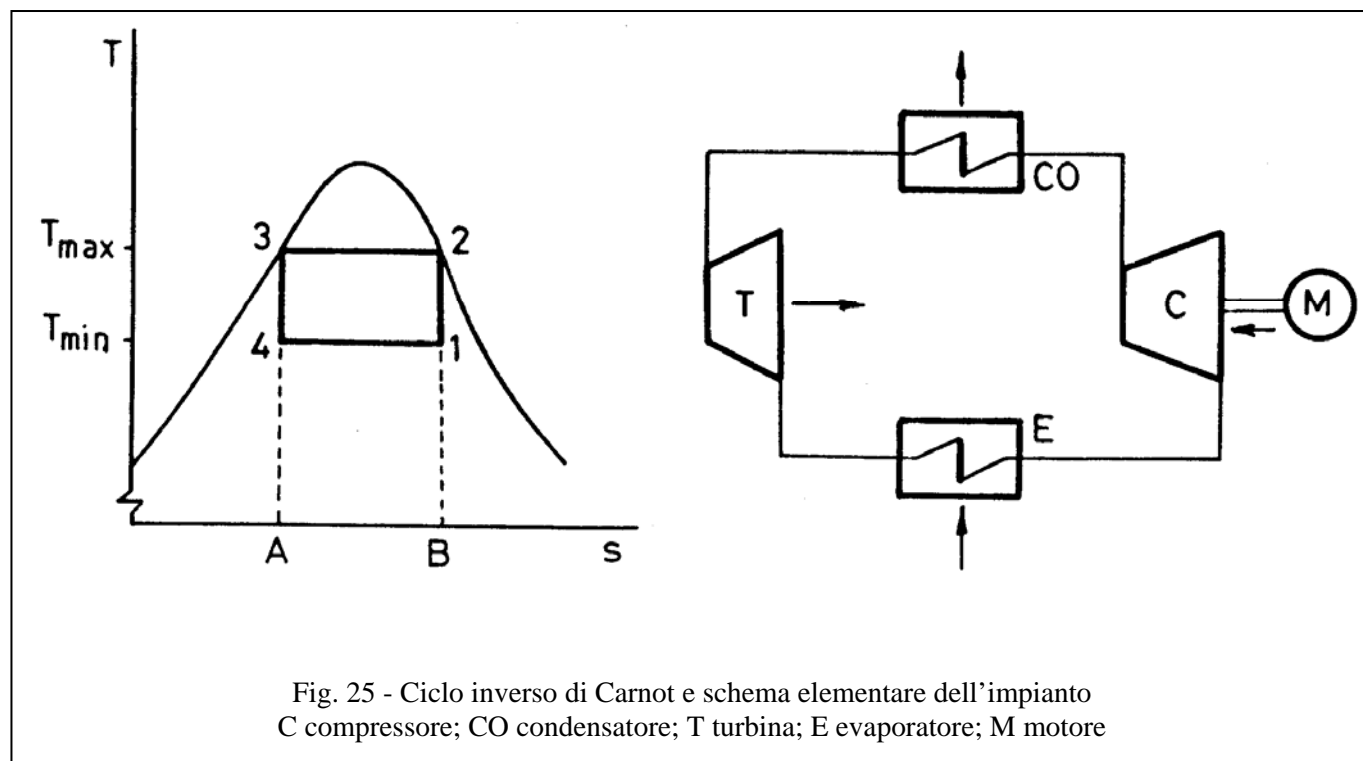
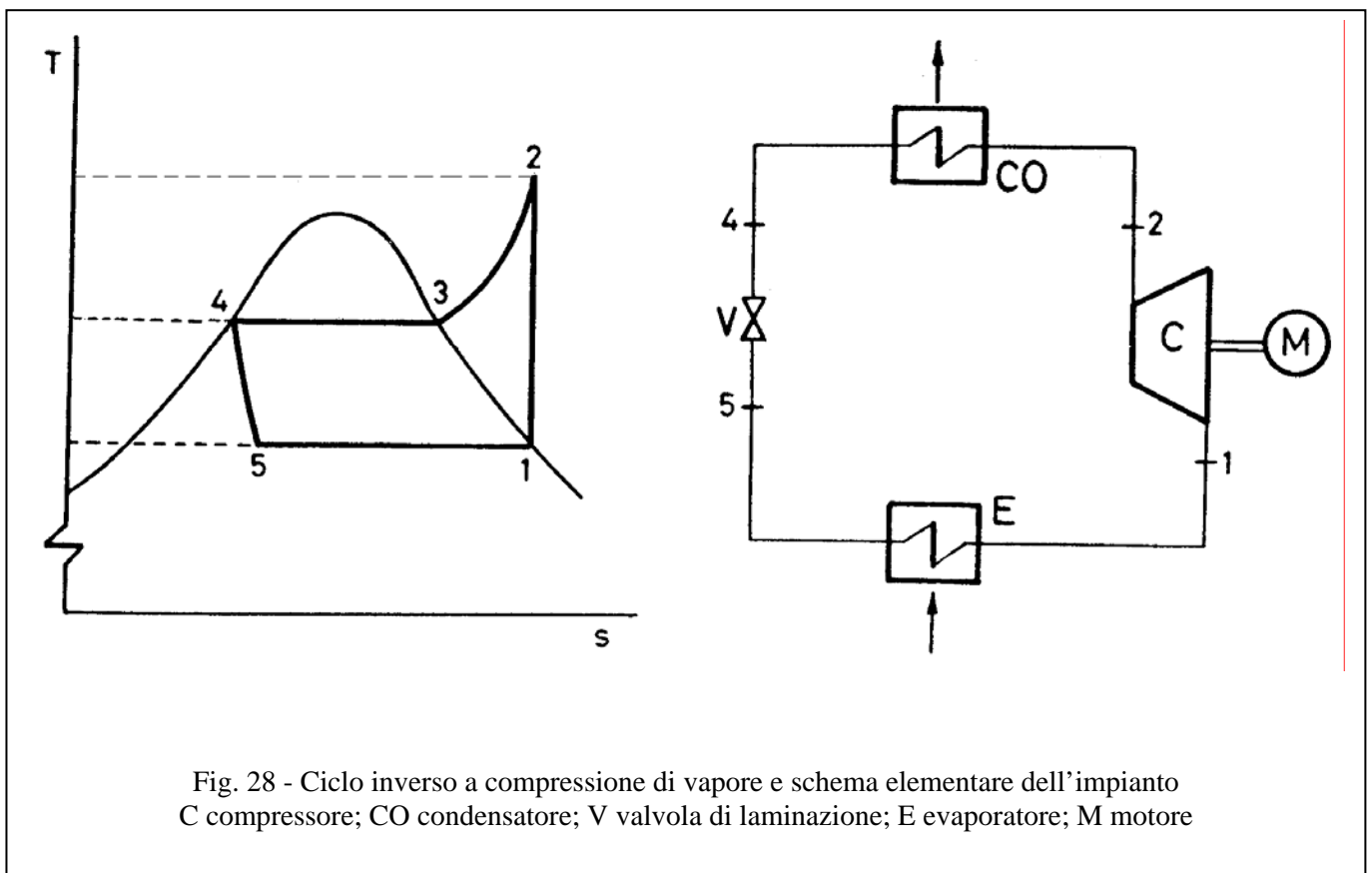
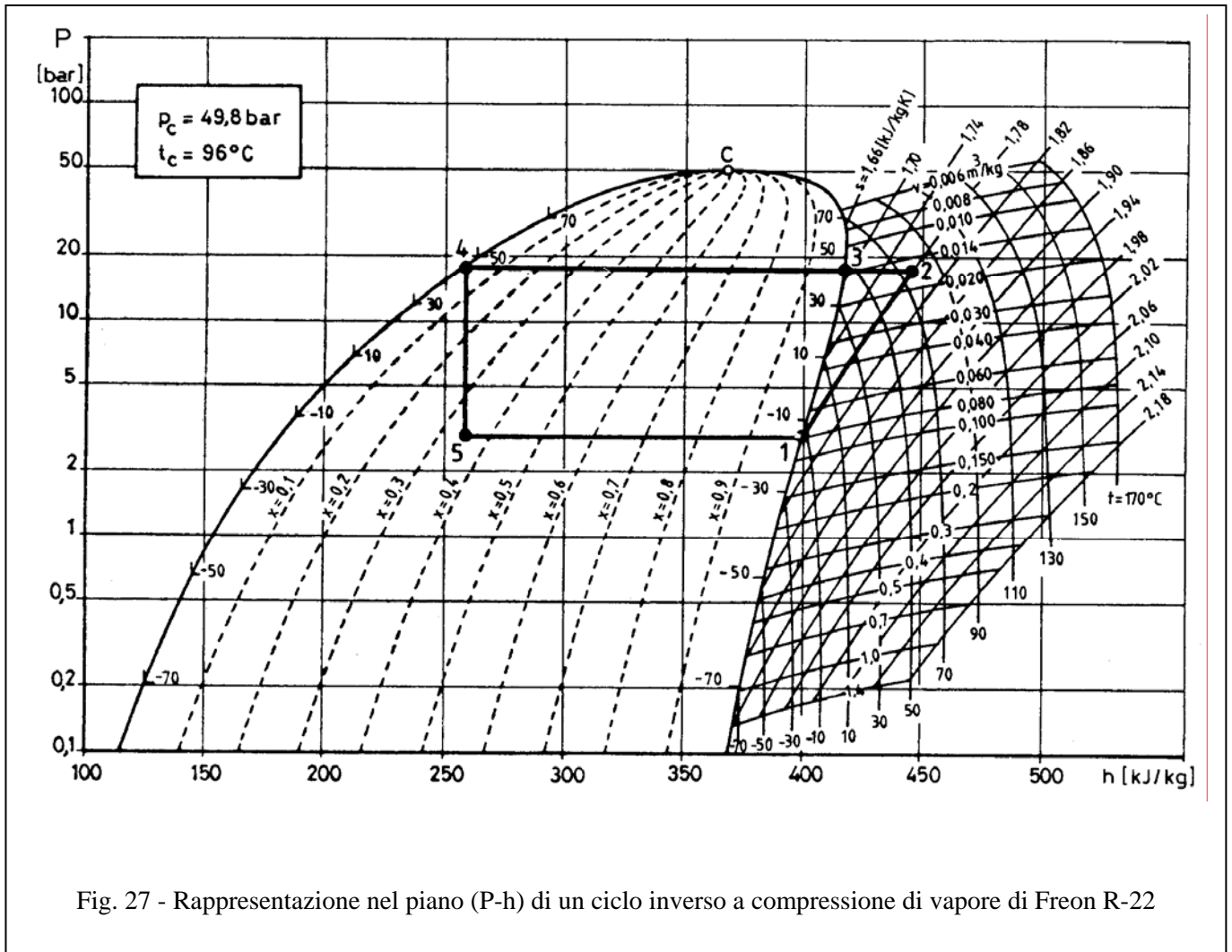


Fig. 24 - Compressore rotante a lobi refrigerato ad aria
impiegato per la sovralimentazione di motori alternativi a combustione interna

FRIGORIFERI E POMPE DI CALORE





t [°C]	p [bar]	h_l [kJ/kg]	h_v [kJ/kg]	s_l [kJ/kg K]	s_v [kJ/kg K]	v_l [dm ³ /kg]	v_v [dm ³ /kg]
- 30	1,195	288,42	1646,64	1,37894	6,96487	1,47548	962,50
- 25	1,515	310,75	1653,82	1,46966	6,88197	1,48931	770,46
- 24	1,587	315,23	1655,22	1,48762	6,86586	1,48762	737,80
- 22	1,738	324,19	1657,98	1,52337	6,83408	1,49782	677,34
- 18	2,076	342,17	1663,35	1,59417	6,77223	1,50944	573,386
- 15	2,362	355,69	1667,24	1,64667	6,72727	1,51836	507,899
- 10	2,908	378,29	1673,46	1,73307	6,65488	1,53365	417,699
- 8	3,152	387,35	1675,85	1,76725	6,62676	1,53992	387,126
- 6	3,412	396,43	1678,19	1,80121	6,59909	1,54628	359,223
- 4	3,688	405,53	1680,46	1,83497	6,57186	1,55273	333,719
0	4,294	423,76	1684,84	1,90188	6,51865	1,56593	288,986
18	8,039	506,62	1701,40	2,19351	6,29716	1,63079	158,860
20	8,574	515,92	1702,91	2,22503	6,27410	1,63863	149,297
22	9,136	525,24	1704,34	2,25640	6,25131	1,64661	140,421
24	9,725	534,58	1705,70	2,28762	6,22878	1,65473	132,172
26	10,343	543,95	1706,98	2,31868	6,20649	1,66301	124,499
28	10,991	553,34	1708,19	2,34960	6,18443	1,67145	117,355
30	11,669	562,75	1709,33	2,38038	6,16259	1,68005	110,697
32	12,379	572,19	1710,38	2,41103	6,14096	1,68882	104,486
34	13,121	581,66	1711,35	2,44155	6,11952	1,69776	98,6862
36	13,896	591,16	1712,24	2,47194	6,09828	1,70690	93,2662
38	14,705	600,69	1713,05	2,50223	6,07721	1,71622	88,1963
40	15,549	610,25	1713,76	2,53240	6,05631	1,72575	83,4498

Proprietà termodinamiche del vapore di ammoniaca saturo nel Sistema Internazionale.

[International Institute of Refrigeration, 1981]

	$(t_s + 20)$	$(t_s + 40)$	$(t_s + 60)$	$(t_s + 80)$	
$p = 6,150$ bar $(t_s = 10^\circ\text{C})$	1748,64	1799,29	1848,18	1896,15	h [kJ/kg]
	6,57646	6,73832	6,88510	7,02100	s [kJ/kg K]
	225,352	244,120	262,113	279,592	v [dm ³ /kg]
$p = 8,574$ bar $(t_s = 20^\circ\text{C})$	1759,72	1812,49	1863,02	1912,34	h [kJ/kg]
	6,46169	6,62507	6,77239	6,90826	s [kJ/kg K]
	164,339	178,298	191,579	204,411	v [dm ³ /kg]
$p = 11,669$ bar $(t_s = 30^\circ\text{C})$	1769,38	1824,49	1876,85	1927,67	h [kJ/kg]
	6,35454	6,52007	6,66840	6,80463	s [kJ/kg K]
	122,337	133,012	143,088	152,765	v [dm ³ /kg]
$p = 15,549$ bar $(t_s = 40^\circ\text{C})$	1777,49	1835,22	1889,60	1942,06	h [kJ/kg]
	6,25369	6,42204	6,57185	6,70881	s [kJ/kg K]
	92,7010	101,075	108,909	116,385	v [dm ³ /kg]

Proprietà termodinamiche del vapore di ammoniaca surriscaldato nel Sistema Internazionale.

[International Institute of Refrigeration, 1981]

t [°C]	p [bar]	h_l [kJ/kg]	h_v [kJ/kg]	s_l [kJ/kg K]	s_v [kJ/kg K]	v_l [dm ³ /kg]	v_v [dm ³ /kg]
- 30	1,00341	172,811	338,150	0,89515	1,57514	0,67198	159,481
- 25	1,23599	177,276	340,429	0,91326	1,57074	0,67858	131,250
- 24	1,28715	178,171	340,883	0,91685	1,56992	0,67993	126,362
- 22	1,39437	179,966	341,787	0,92400	1,56832	0,68267	117,240
- 18	1,62941	183,567	343,587	0,93816	1,56532	0,68826	101,303
- 15	1,82482	186,279	344,927	0,94868	1,56323	0,69258	91,0717
- 10	2,18986	190,822	347,141	0,96601	1,56004	0,70001	76,6897
- 8	2,35051	192,647	348,020	0,97287	1,55885	0,70308	71,7263
- 6	2,51998	194,477	348,893	0,97971	1,55772	0,70619	67,1514
- 4	2,69858	196,313	349,762	0,98650	1,55663	0,70936	62,9292
0	3,08439	200,000	351,485	1,00000	1,55458	0,71587	55,4183
18	5,35687	216,905	358,943	1,05934	1,54719	0,74843	32,5557
20	5,67023	218,821	359,737	1,06581	1,54651	0,75243	30,7945
22	5,99702	220,745	360,522	1,07227	1,54585	0,75651	29,1461
24	6,33761	222,679	361,299	1,07871	1,54521	0,76069	27,6019
26	6,69234	224,622	362,067	1,08514	1,54459	0,76497	26,1539
28	7,06159	226,575	362,826	1,09155	1,54399	0,76934	24,7950
30	7,44572	228,538	363,575	1,09795	1,54340	0,77382	23,5186
32	7,84509	230,513	364,313	1,10434	1,54282	0,77841	22,3185
34	8,26009	232,499	365,041	1,11072	1,54225	0,78312	21,1893
36	8,69108	234,498	365,758	1,11710	1,54168	0,78794	20,1260
38	9,13845	236,509	366,463	1,12347	1,54113	0,79290	19,1237
40	9,60259	238,533	367,155	1,12984	1,54057	0,79798	18,1783

Proprietà termodinamiche del vapore di freon 12 (R 12) saturo nel Sistema Internazionale.
[International Institute of Refrigeration, 1981]

	$(t_s + 5)$	$(t_s + 10)$	$(t_s + 15)$	$(t_s + 20)$	
$p = 5,6702$ bar $(t_s = 20$ °C)	363,27	366,78	370,28	373,76	h [kJ/kg]
	1,5585	1,5701	1,5816	1,5928	s [kJ/kg K]
	31,644	32,472	33,281	34,075	v [dm ³ /kg]
$p = 6,6923$ bar $(t_s = 26$ °C)	365,70	369,31	372,89	376,45	h [kJ/kg]
	1,5566	1,5684	1,5799	1,5911	s [kJ/kg K]
	26,902	27,629	28,338	29,031	v [dm ³ /kg]
$p = 7,4457$ bar $(t_s = 30$ °C)	367,68	370,95	374,59	378,21	h [kJ/kg]
	1,5555	1,5673	1,5789	1,5902	s [kJ/kg K]
	24,210	24,880	25,533	26,170	v [dm ³ /kg]
$p = 8,6911$ bar $(t_s = 36$ °C)	369,58	373,36	377,09	380,80	h [kJ/kg]
	1,5540	1,5659	1,5775	1,5888	s [kJ/kg K]
	20,745	21,344	21,925	22,490	v [dm ³ /kg]

Proprietà termodinamiche del vapore di freon 12 (R 12) surriscaldato nel Sistema Internazionale.
[International Institute of Refrigeration, 1981]

t [°C]	p [bar]	h_l [kJ/kg]	h_v [kJ/kg]	s_l [kJ/kg K]	s_v [kJ/kg K]	v_l [dm ³ /kg]	v_v [dm ³ /kg]
- 30	1,63401	166,141	393,145	0,86976	1,80335	0,72450	135,905
- 25	2,00887	171,607	395,337	0,89190	1,79349	0,73253	111,907
- 24	2,09124	172,708	395,769	0,89630	1,79159	0,73418	107,747
- 22	2,26382	174,920	396,626	0,90509	1,78786	0,73751	99,9777
- 18	2,64181	179,377	398,312	0,92259	1,78065	0,74434	86,3894
- 15	2,95577	182,749	399,551	0,93564	1,77547	0,74962	77,6560
- 10	3,54159	188,427	401,563	0,95725	1,76719	0,75874	65,3646
- 8	3,79916	190,718	402,348	0,96585	1,76400	0,76251	61,1187
- 6	4,07071	193,021	403,122	0,97442	1,76088	0,76634	57,2031
- 4	4,35672	195,335	403,883	0,98297	1,75781	0,77026	53,5877
0	4,97406	200,000	405,369	1,00000	1,75185	0,77832	47,1520
18	8,59810	221,614	411,345	1,07559	1,72725	0,81919	27,5261
20	9,09647	224,083	411,927	1,08390	1,72467	0,82428	26,0114
22	9,61591	226,567	412,490	1,09220	1,72212	0,82951	24,5933
24	10,1570	229,067	413,034	1,10048	1,71959	0,83488	23,2644
26	10,7202	231,582	413,557	1,10876	1,71707	0,84040	22,0178
28	11,3061	234,114	414,060	1,11703	1,71456	0,84606	20,8475
30	11,9153	236,662	414,540	1,12530	1,71206	0,85190	19,7476
32	12,5484	239,228	414,997	1,13355	1,70956	0,85790	18,7132
34	13,2059	241,812	415,430	1,14181	1,70706	0,86409	17,7394
36	13,8885	244,416	415,837	1,15007	1,70456	0,87047	16,8217
38	14,5966	247,039	416,218	1,15833	1,70205	0,87707	15,9564
40	15,3310	249,684	416,571	1,16659	1,69952	0,88388	15,1395

Proprietà termodinamiche del vapore di freon 22 (R 22) saturo nel Sistema Internazionale.
[International Institute of Refrigeration, 1981]

	$(t_s + 10)$	$(t_s + 20)$	$(t_s + 30)$	$(t_s + 40)$	
$p = 6,8047$ bar $(t_s = 10$ °C)	416,45 1,7642 36,657	423,98 1,7895 38,511	431,48 1,8138 40,302	438,96 1,8373 42,042	h [kJ/kg] s [kJ/kg K] v [dm ³ /kg]
$p = 9,0965$ bar $(t_s = 20$ °C)	420,00 1,7518 27,563	427,93 1,7775 29,035	435,77 1,8021 30,447	443,57 1,8259 31,811	h [kJ/kg] s [kJ/kg K] v [dm ³ /kg]
$p = 11,915$ bar $(t_s = 30$ °C)	423,17 1,7401 21,033	431,56 1,7664 22,238	439,79 1,7915 23,382	447,93 1,8156 24,479	h [kJ/kg] s [kJ/kg K] v [dm ³ /kg]
$p = 15,331$ bar $(t_s = 40$ °C)	425,88 1,7288 16,240	434,81 1,7560 17,254	443,50 1,7817 18,205	452,03 1,8062 19,109	h [kJ/kg] s [kJ/kg K] v [dm ³ /kg]

Proprietà termodinamiche del vapore di freon 22 (R 22) surriscaldato nel Sistema Internazionale.
[International Institute of Refrigeration, 1981]

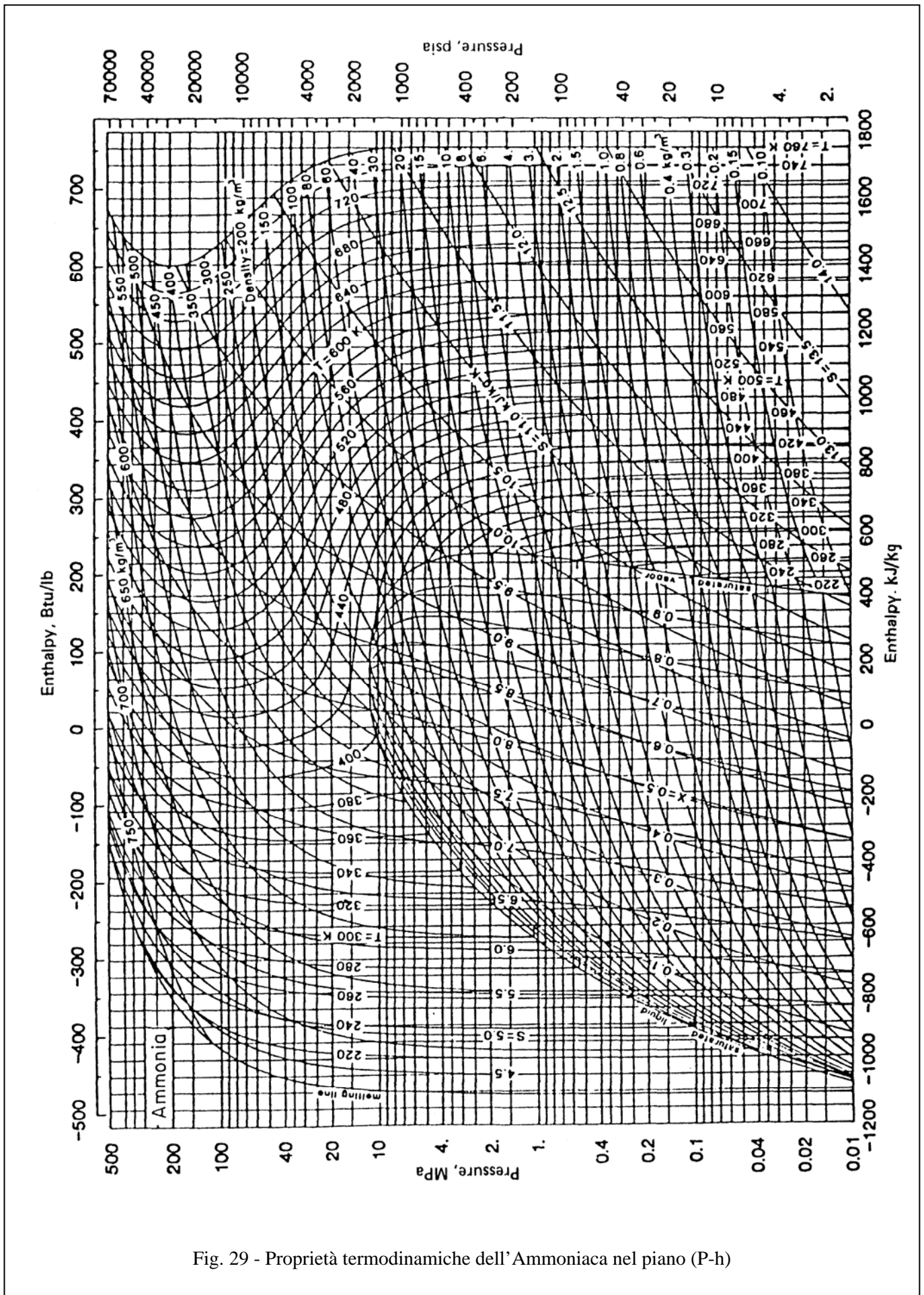


Fig. 29 - Proprietà termodinamiche dell' Ammoniaca nel piano (P-h)

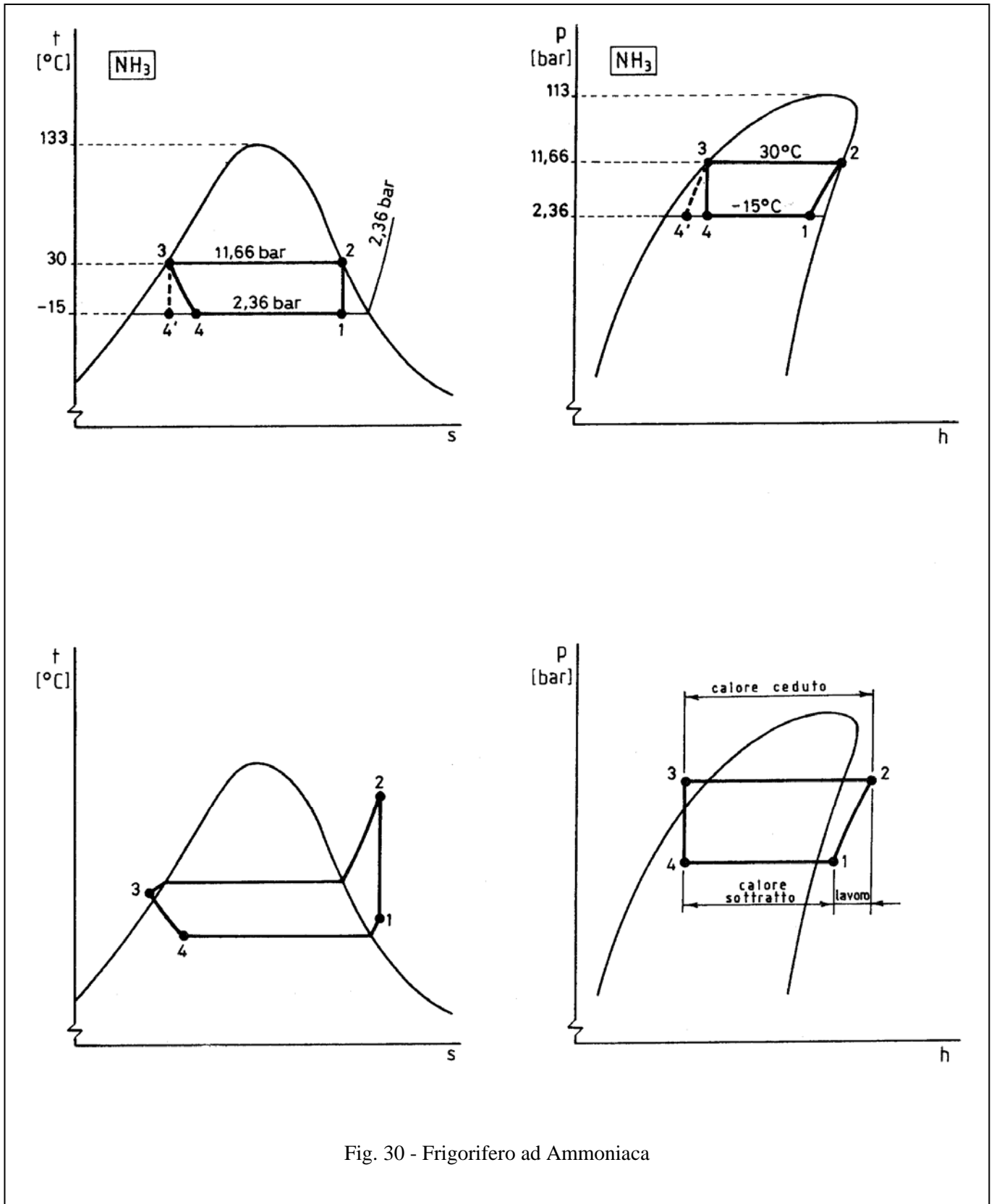


Fig. 30 - Frigorifero ad Ammoniaca

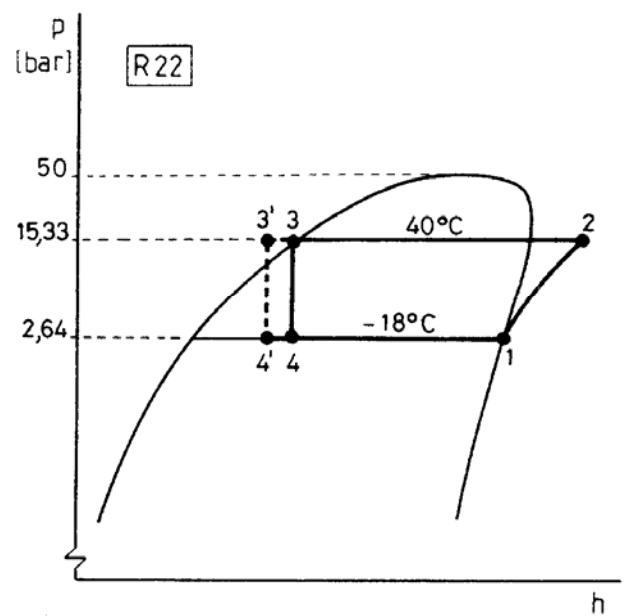
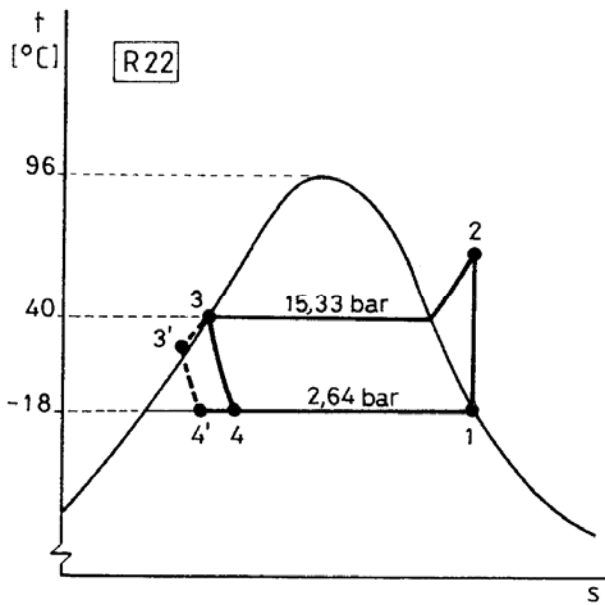
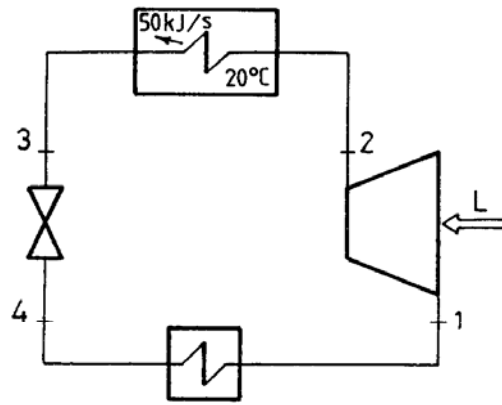


Fig. 31 - Pompa di calore a Freon R22

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