CHAPTER VII

OPTIMIZATION OF AN EXISTING TOPPING COLUMN

With the successful development of a computer model for an existing topping column as explained in Chapter VI, operational results of the topper conditions other than the present conditions may be simulated and compared, so as to improve the topper operation while satisfying the basic constraints of the refining operation (such as product specifications, etc.). So far a reliable and efficient method to solve the above constrained optimization problem rigorously has yet to be devised. Therefore, in the present work the existing topping column is to be optimized to a certain degree with the aid of the computer model by relying on a simple trial-and-error scheme. The indicated improvement in operation should, nevertheless, provide useful data for refinery planning and management. It should be noted that the scope of the present study is necessarily limited only to the topping column, though the same concept might be expanded to cover the whole refinery plant. This on the other hand will require a team effort and considerably more manhours. Furthermore, to arrive at a sound management decision would have to take into account such external as well as technical factors as seasonal demands, official pricings, sources of crude oils and their characteristics and so on.

7.1 Choice of Operating Variables and Objective of Optimization

Two major objectives in refinery operation are: to minimize energy comsumption, and to maximize sales value of all products. To do this the operating variables that should be investigated include feed condition of entering crude, stripping steam rates, pumparound reflux duties, top reflux and condenser duties, and withdrawal rates.

In order to reduce the complexity of the present optimum operation problem, some of the above variables are taken to be fixed and only the more important ones are chosen as operating variables to be optimized. Thus the present optimization of the theoretical analogue column assumes the following conditions or variables as fixed:

a) Crude properties and feed rate

b) Column pressure and the pressure drop across each stage

c) Molal withdrawal rates of sidestream products

d) Stripping steam rates

e) Molal pumparound rates

f) Internal reflux duties

g) Condenser temperature and pressure

The following operating variables are investigated:

a) Crude thermal condition (at the topper inlet)

b) Molal reflux ratio of the topper

The topping column performance will significantly be affected by any change in the crude feed temperature and the top reflux ratio, as evident from the resulting column temperature and molal flow profiles, and thermal duties of the reflux accumulator and condenser. In addition, molal flow rates of the LSR naphtha at the top and reduced crude at the bottom will change, even though those of the side-stream products are kept constant. After a reasonable number of operating conditions have been chosen and the corresponding simulation results obtained, and economic evaluation is next performed that takes into account the operating cost (the fuel costs) of the crude heating furnace (pipestill) and condenser, as well as the sales value (product values) of the LSR naphtha and reduced crude. Though the present approach may not accurately estimate the improved benefits, it is however expected to yield valuable information on how the present topping operation might be improved and what to expect roughly from such an improvement.

7.2 Product Specifications

Any change in the above operating variables will naturally affect the resulting product quality to some extent. Therefore it is of utmost important that under no circumstances will a new operating condition be allowed to yield distillation that violate existing product specifications. In other words, only operating conditions that yield product specifications within the acceptable ranges will be evaluated economically.

The product specifications used to determine the suitability or acceptability of an operating conditions are shown in Table 21. It should be mentioned that regarding to the product specifications, not only the ASTM distillation must be considered by other properties such as flash point, Reid vapor pressure, etc., should also be check-

Table 21 Product specifications of the existing refinery plant

Product	Specification	
LSR naphtha	10% ASTM	< 150°F
	50% ASTM	150 - 230°F
	End Point	< 280°F
	RV.P.	< 9 psi
HSR naphtha	End Point	< 400°F
Kerosene	Flash Point	< 130°F
	90% ASTM	< 510°F
Diesel Oil	Flash Point	> 200°F
	90% ASTM	< 650°F
Gas Oil	Flash Point	> 200°F
Reduced Crude	Flash Point	> 140°F
	Vis.SSU@ 122°F	1000 - 1300

ed. However, these properties were not checked in the present work because of lack of reliable and simple correlations.

7.3 Summary of Simulation Results

The operating condition investigated in Chapter VI is taken as the reference condition. A number of new operating conditions to be simulated are chosen by simple adding appropriate deviations to the reference values of the two operating variables of interest. Table 22 summarizes all operating conditions investigated. As evident from Table 22, some of the operating conditions are judged inappropriate when the computer model fail to converge.

For the cases in which simulation results (convergences) have been obtained, Table 23 summarizes the thermal duties of the reflux accumulator and condenser, and the molal flow rates of the LSR naphtha and reduced crude stream. The corresponding product TBP distillation curves are shown in Figs. 33a-m, and the resulting product ASTM distillation data are tabulated in the Table 24.

According to the product specifications in Table 21, the operating conditions of run no. A600-423, A600-470, and A600-517 were not acceptable due to the low 50% ASTM point of the LSR naphth. Thus the economic evaluation for these three runs is dispensable.

7.4 Optimization Results

As mentioned earlier, the objective function to be optimized consists of two major items. The first is the increase or decrease in operating costs (associated with the thermal duties and fuel costs) compared to the existing operating condition. The second is

Table 22 Summary of Operating Conditions Investigated and Convergence

Run no.	Operating Variables		Convergence
	Crude feed temp.[°F]	Molal reflux ratio	[Yes or No]
A600-423	600	2.364	Yes
A600-470	600	2.128	Yes
A600-517	600	1.934	Yes
A620-423	620	2.364	Yes
A620-470	620	2.128	Yes
A620-517	620	1.934	Yes
A640-423	640	2.364	Yes
A640-470	640	2.128	Yes
A640-517	640	1.934	Yes
A660-423	660	2.364	Yes
A660-470*	660	2,128	Yes
A660-517	660	1.934	Yes
A680-423	680	2.364	Yes
A680-470	680	2.128	No
A680-517	680	1.934	No
A700-423	700	2.364	No
A700-470	700	2.128	No
A700-517	700	1.934	No

* Reference operating condition

Table 23 Summary of Thermal Duties and Molal Flow Rates of Interest

Run no.	Thermal Duty [MMBtu/h]		Molal Flow Rate [lb mol/h]	
	Accumulator	Condenser	LSR naphtha	Reduced crude
A600-423	29.169	7.110	385.01	543.17
A600-470	28.522	8.217	428.26	515.67
A600-517	27.895	9.275	467.78	490.83
A620-423	32.883	9.007	455.09	494.81
A620-470	32.113	10.242	501.78	466.88
A620-517	31.392	11.426	539.28	441.80
A640-423	36.744	10.914	524.84	450.72
A640-470	35.871	12.276	565.79	422.92
A640-517	35.038	13.582	601.46	398.30
A660-423	40.883	12.194	564.71	409.95
A660-470	39.888	14.370	623.48	382.68
A660-517	38.932	15.809	657.68	358.34
A680-423	45.033	14.756	633.52	374.60

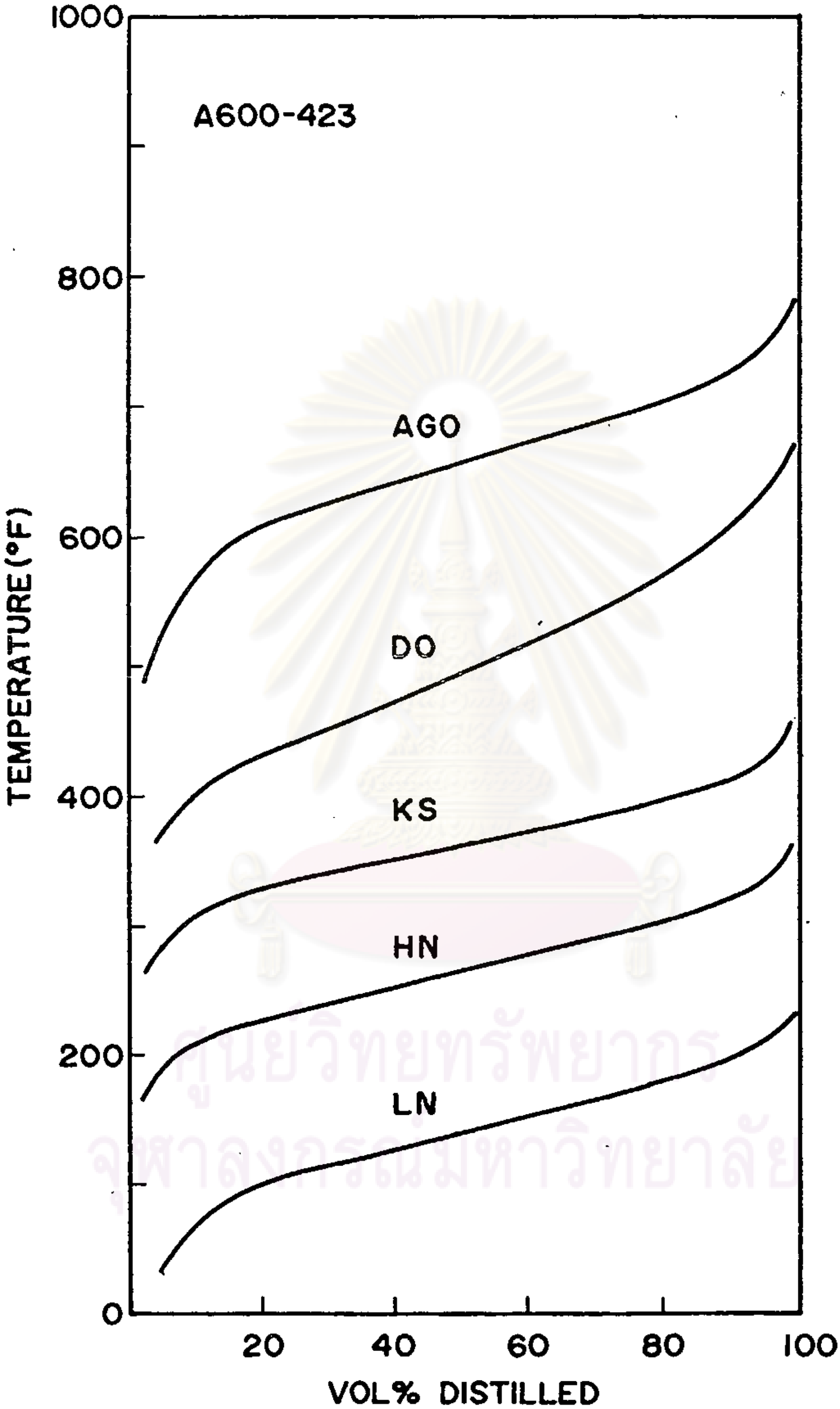
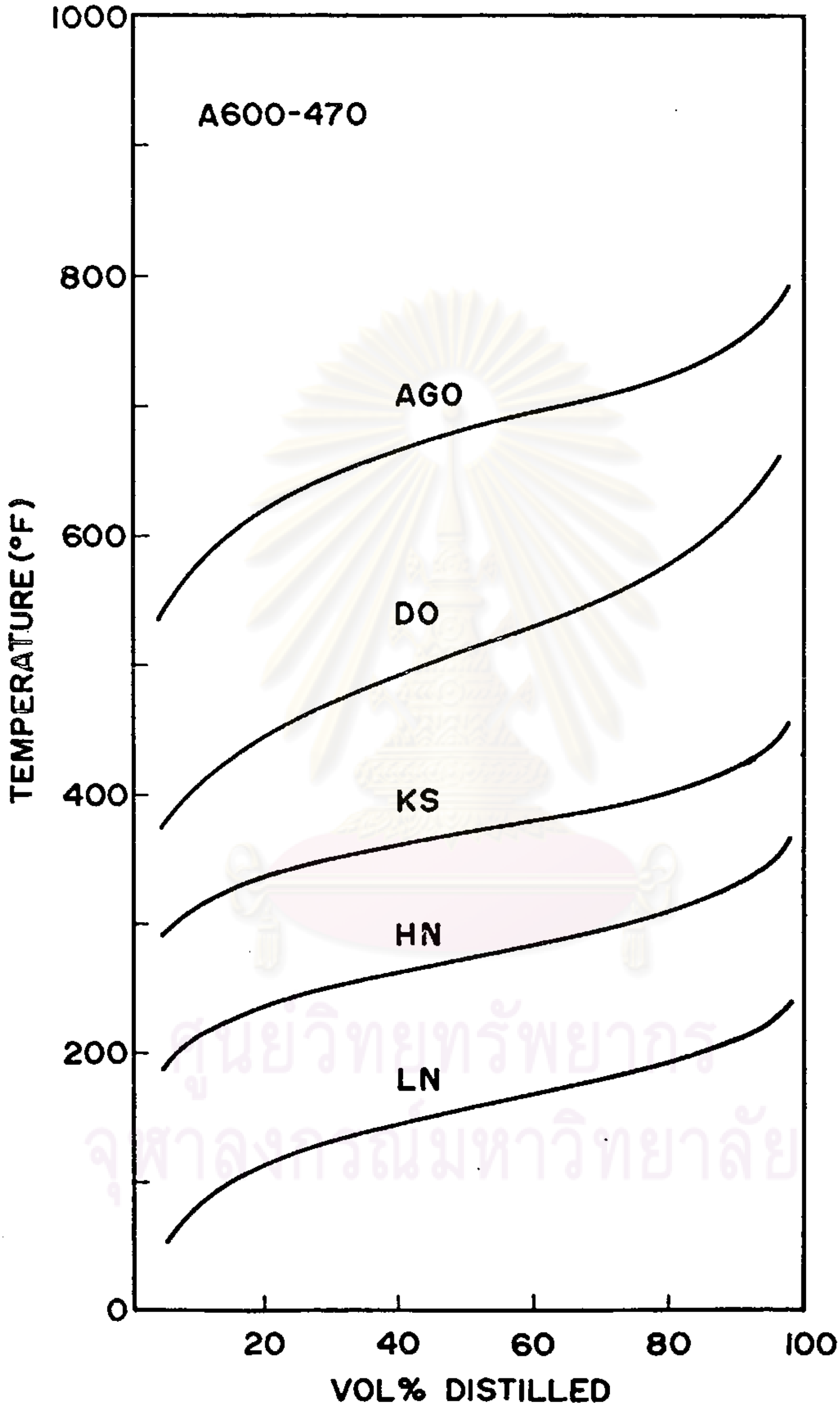

A600-423
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33a



A600-470
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33b

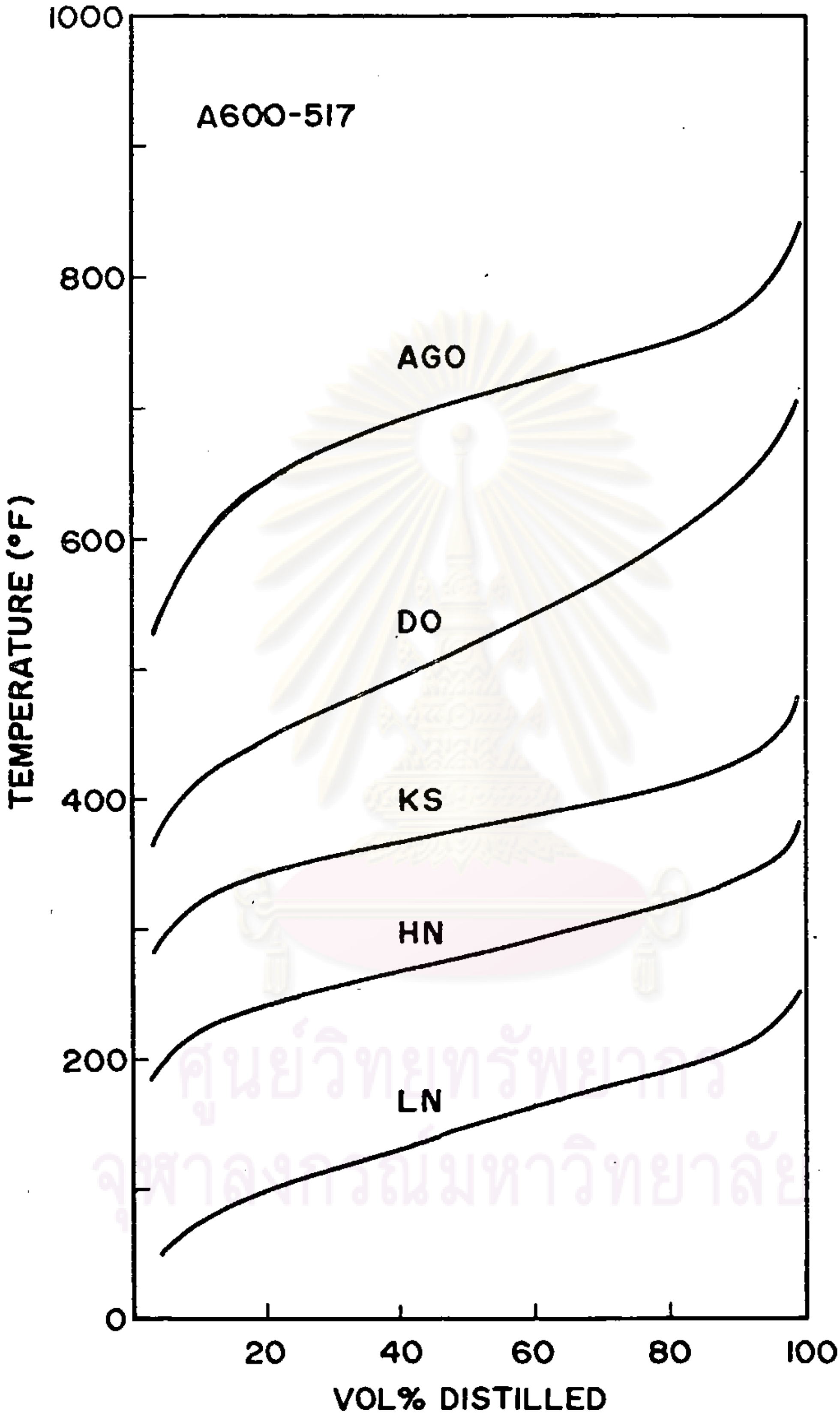

A600-517
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
0
200
400
600
800
1000
20
40
60
80
100
VOL% DISTILLED

Fig.33c

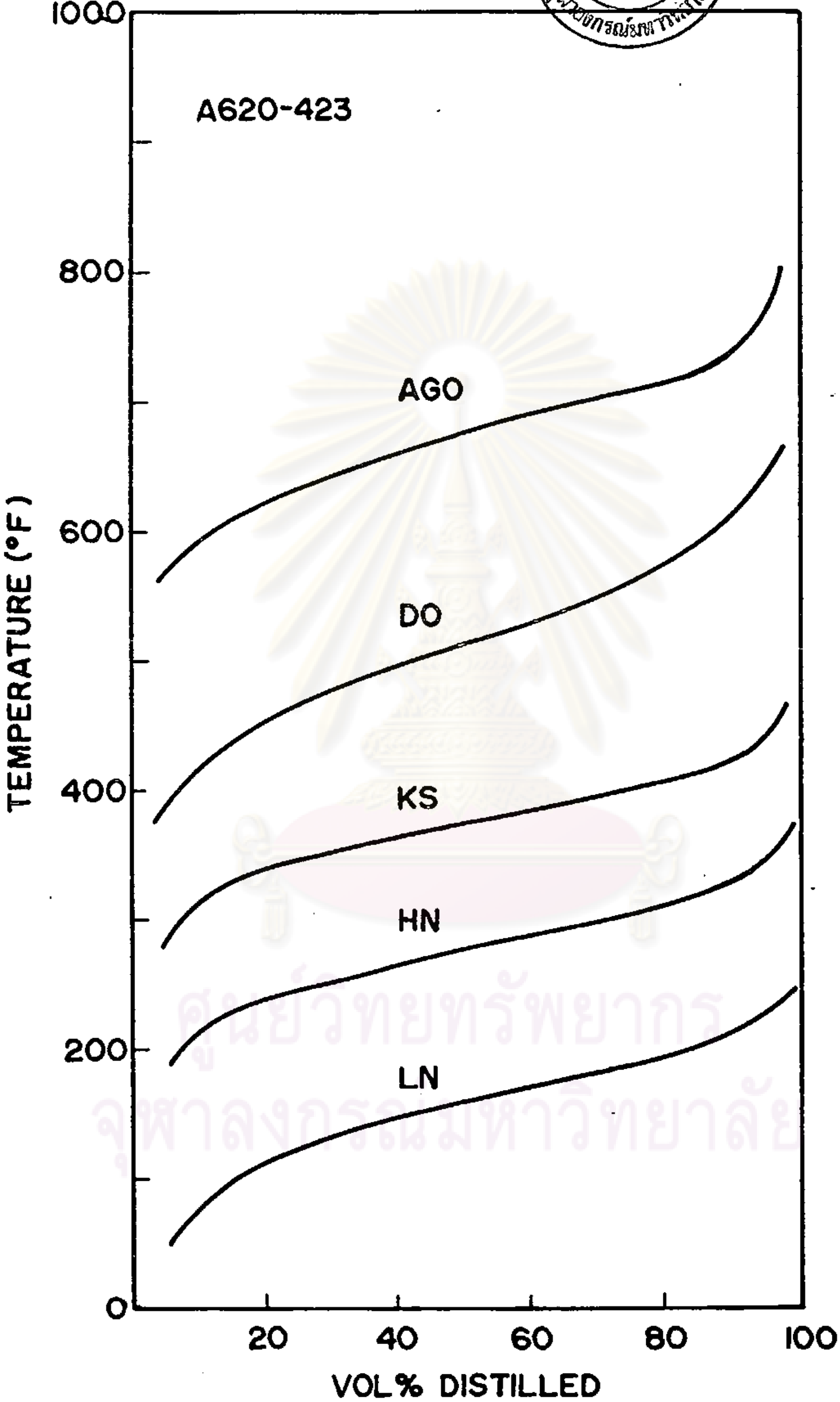

A620-423
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33d

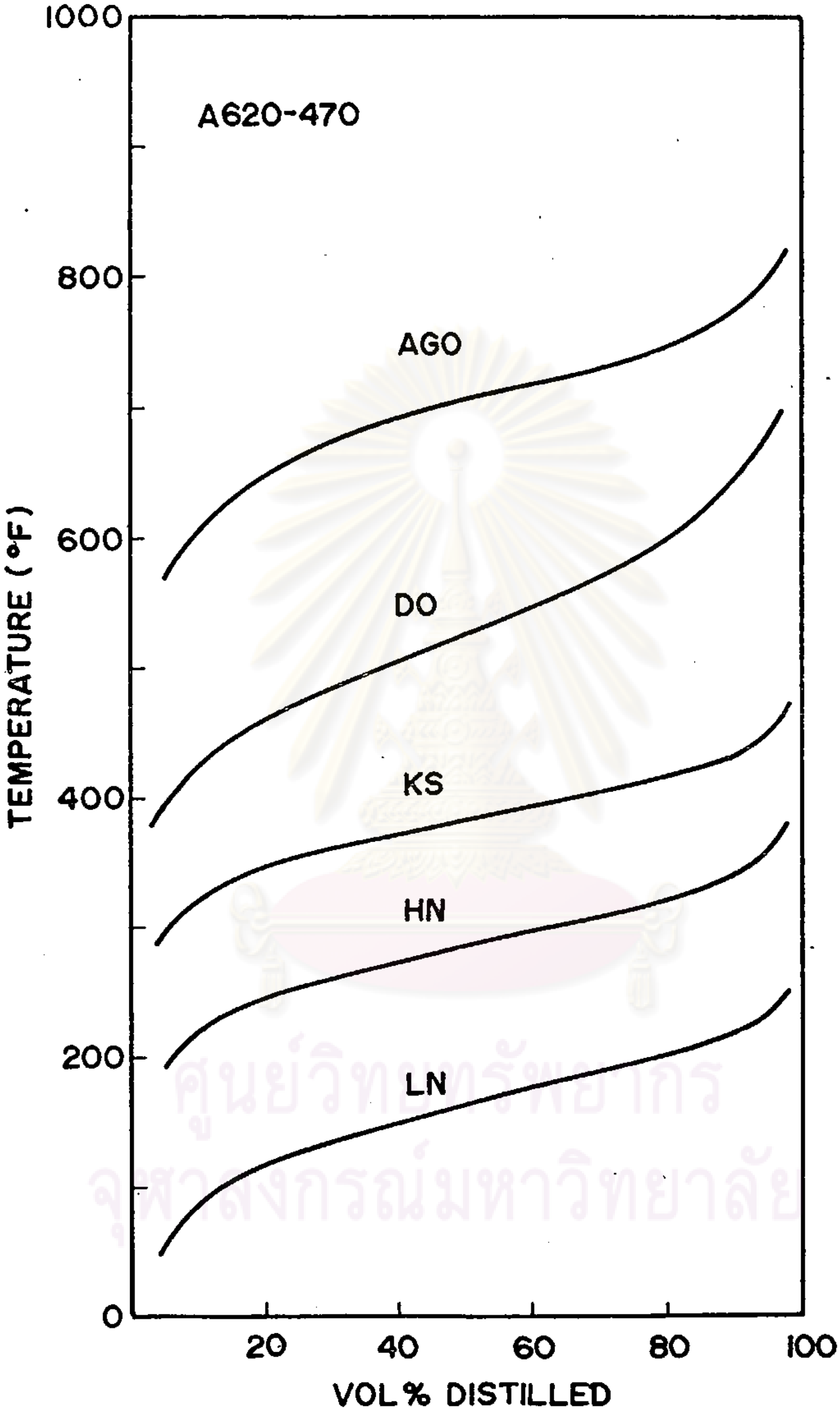

A620-470
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL % DISTILLED

Fig.33e

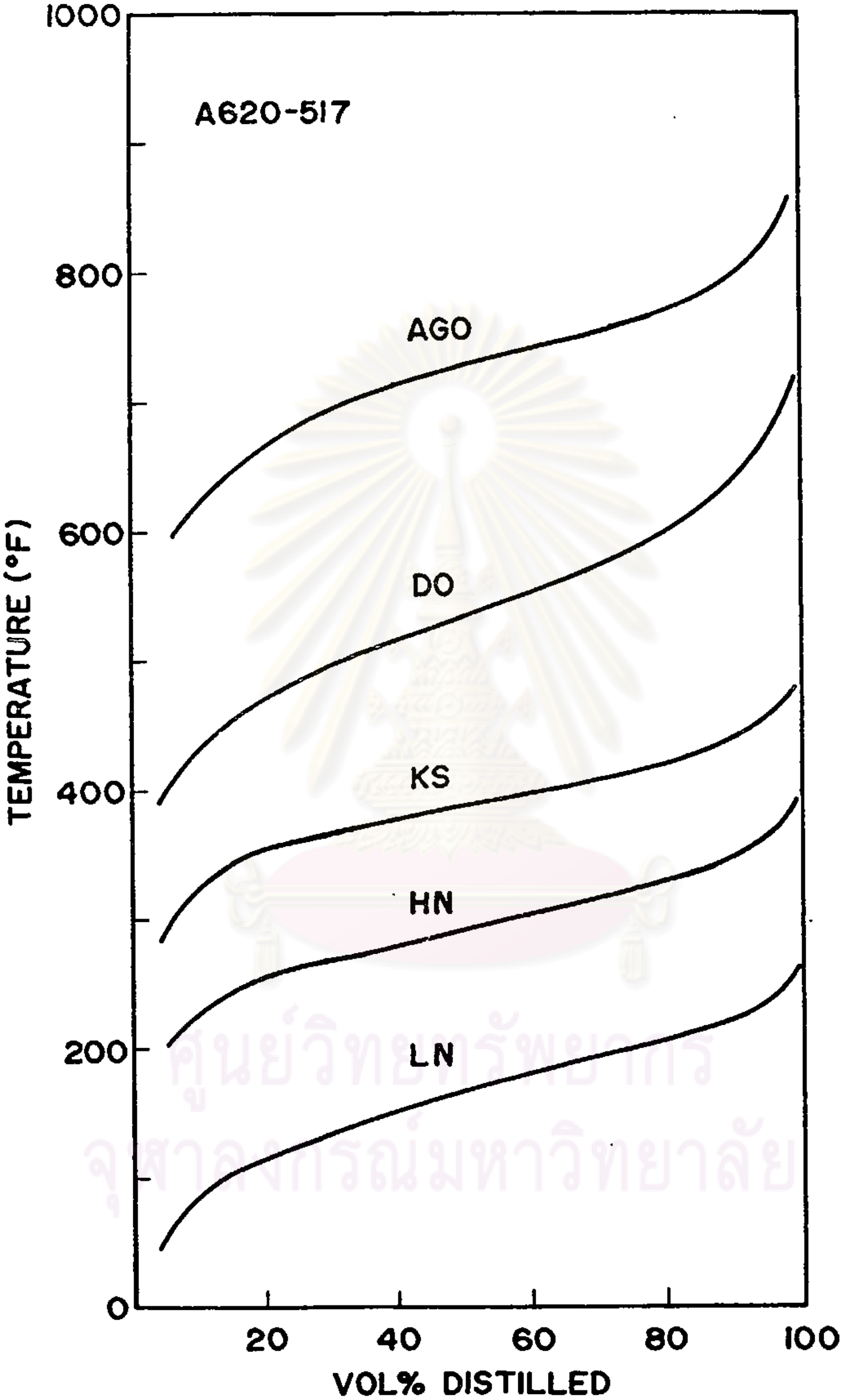

A620-517
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
VOL% DISTILLED
0
200
400
600
800
1000
20
40
60
80
100

Fig.33f

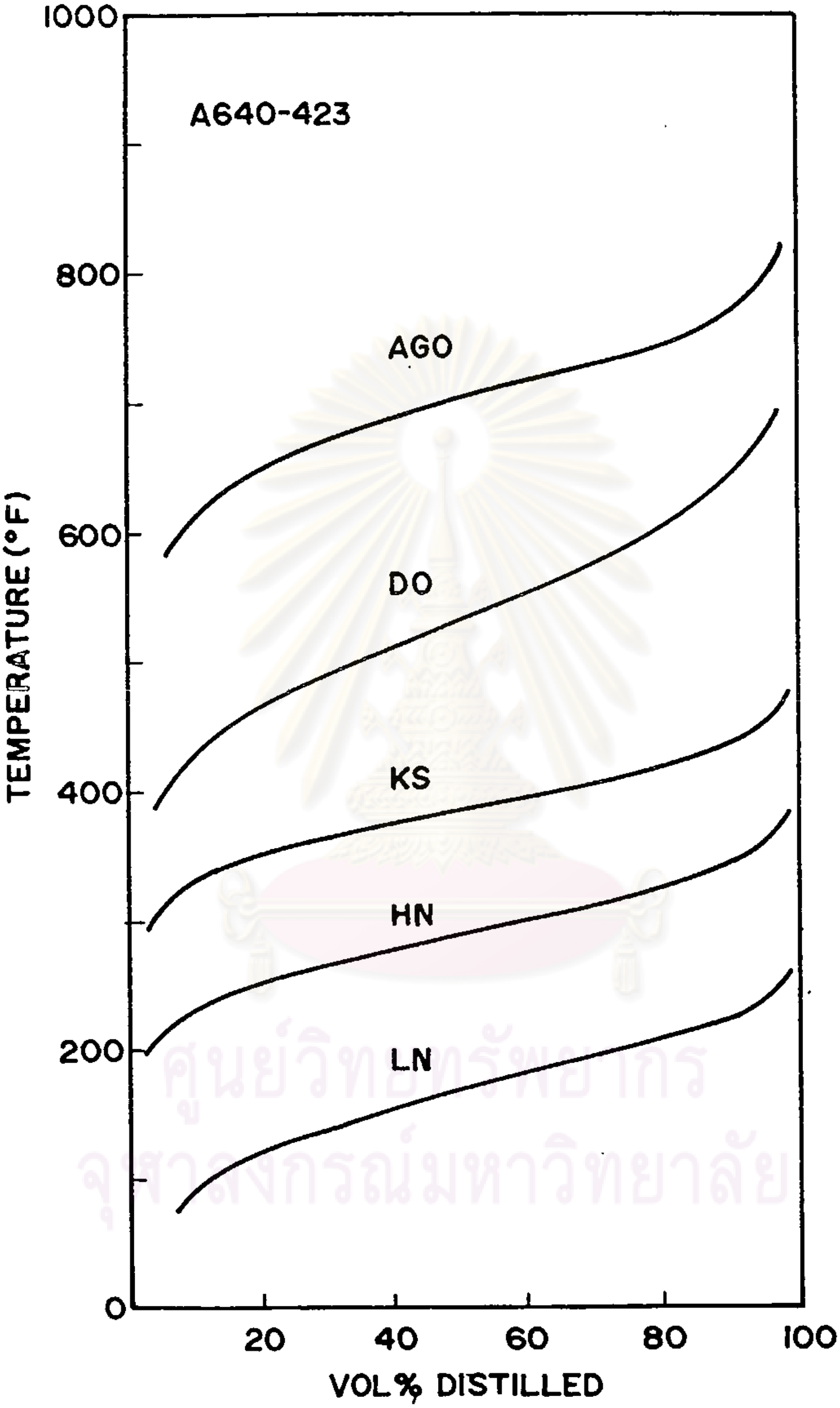

A640-423
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33g

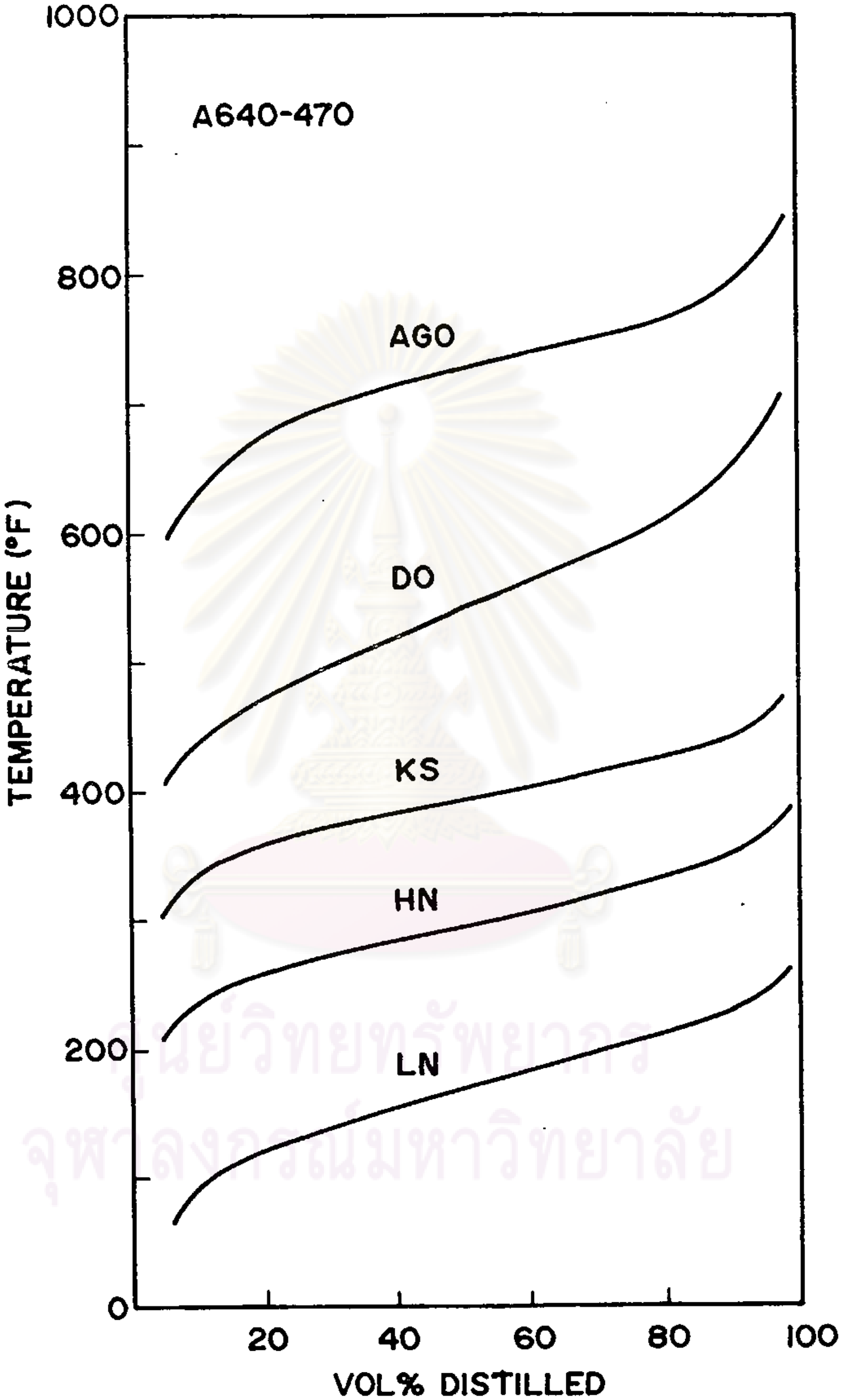

A640-470
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33h

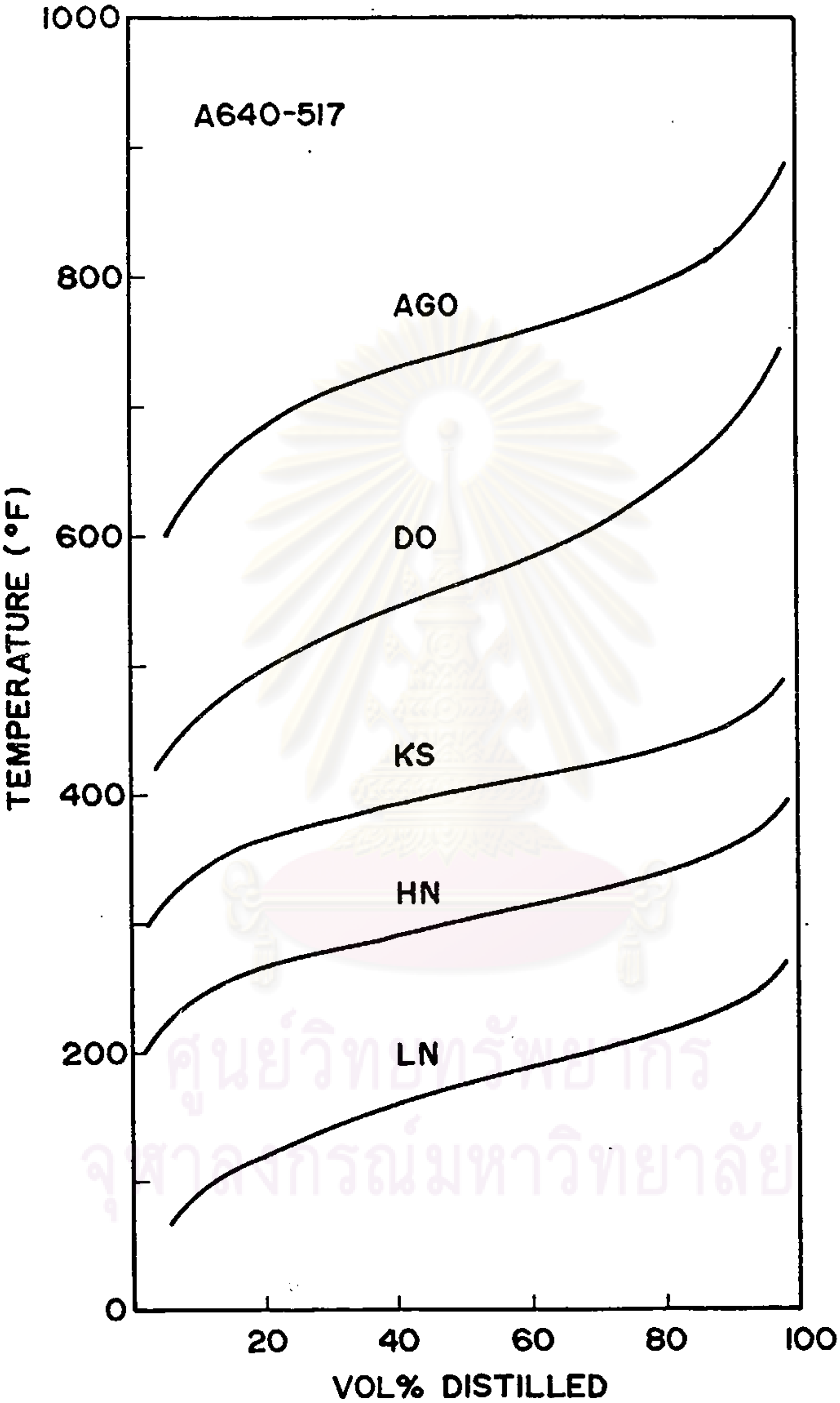

A640-517
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33i

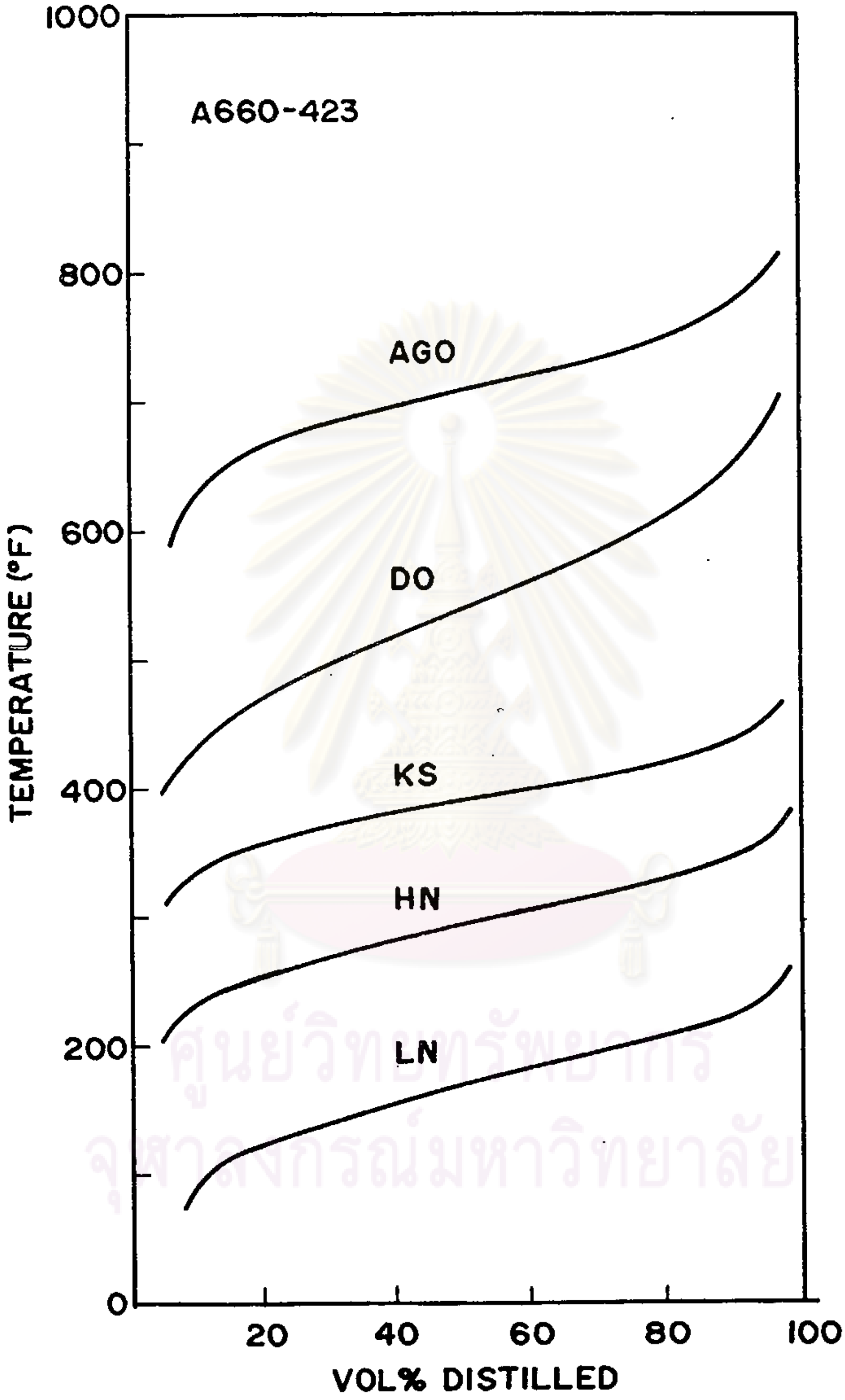

A660-423
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33j

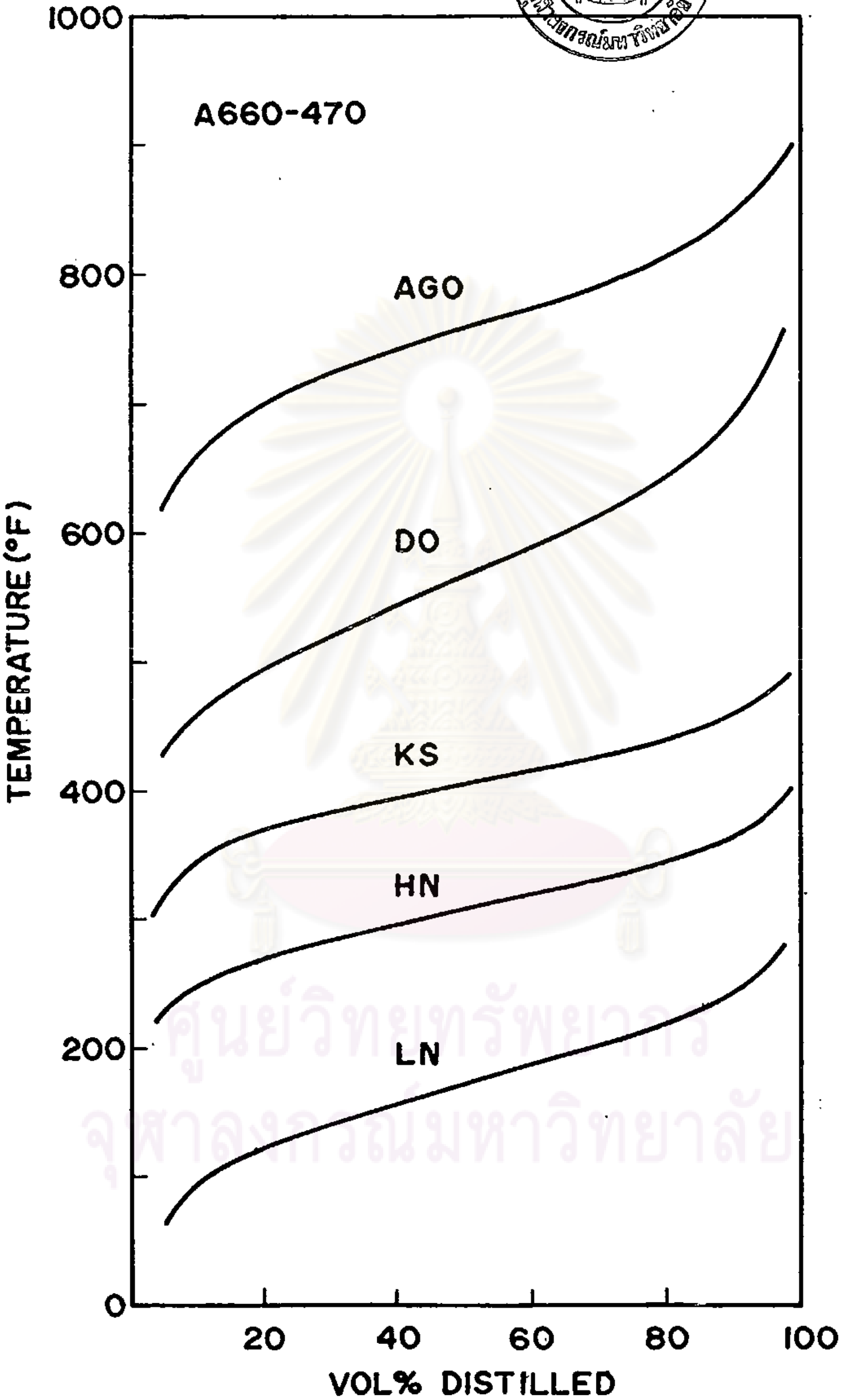

A660-470
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
0
200
400
600
800
1000
20
40
60
80
100
VOL% DISTILLED

Fig.33k

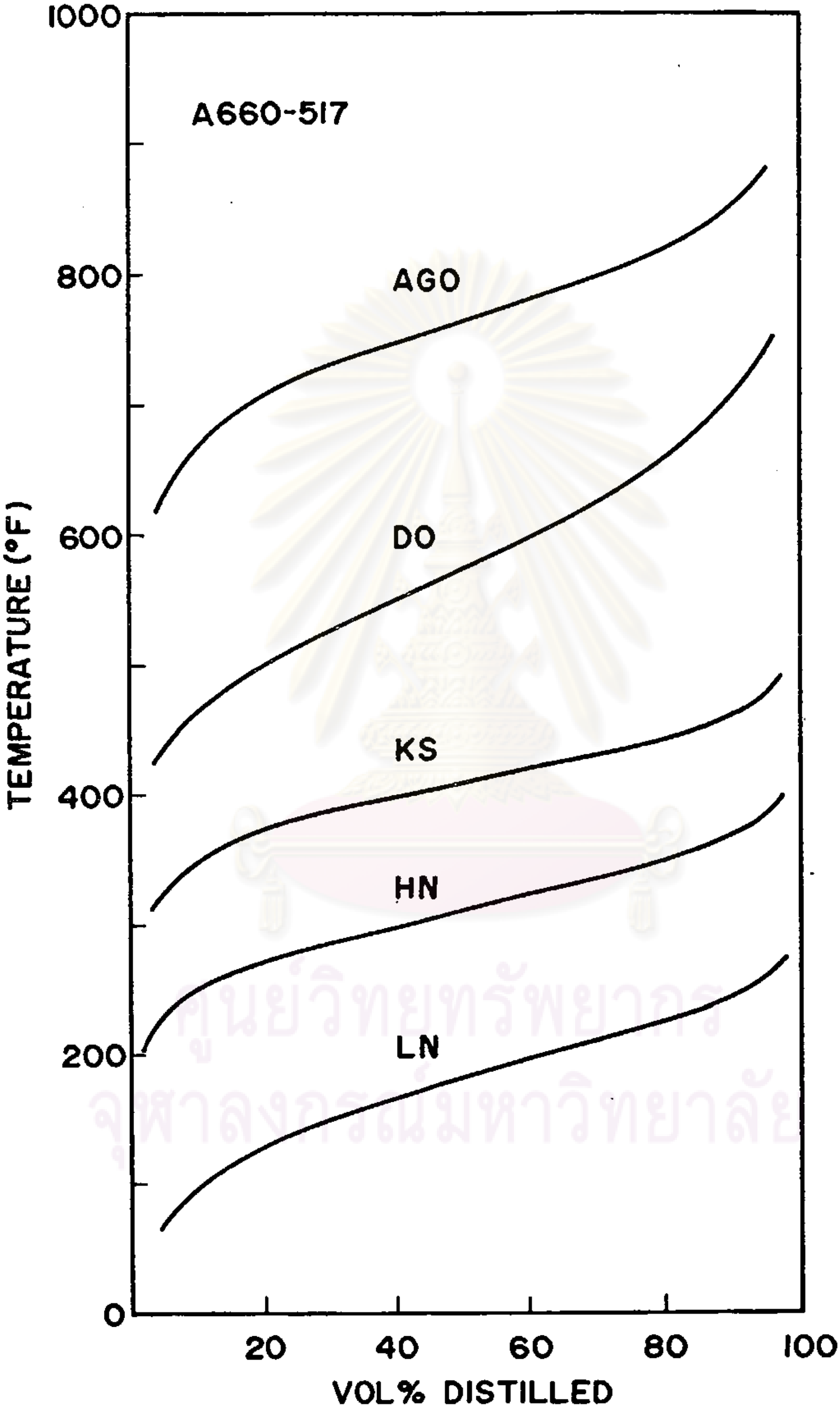

A660-517
AGO
DO
KS
HN
LN
1000
800
600
400
200
0
TEMPERATURE (°F)
20
40
60
80
100
VOL% DISTILLED

Fig.331

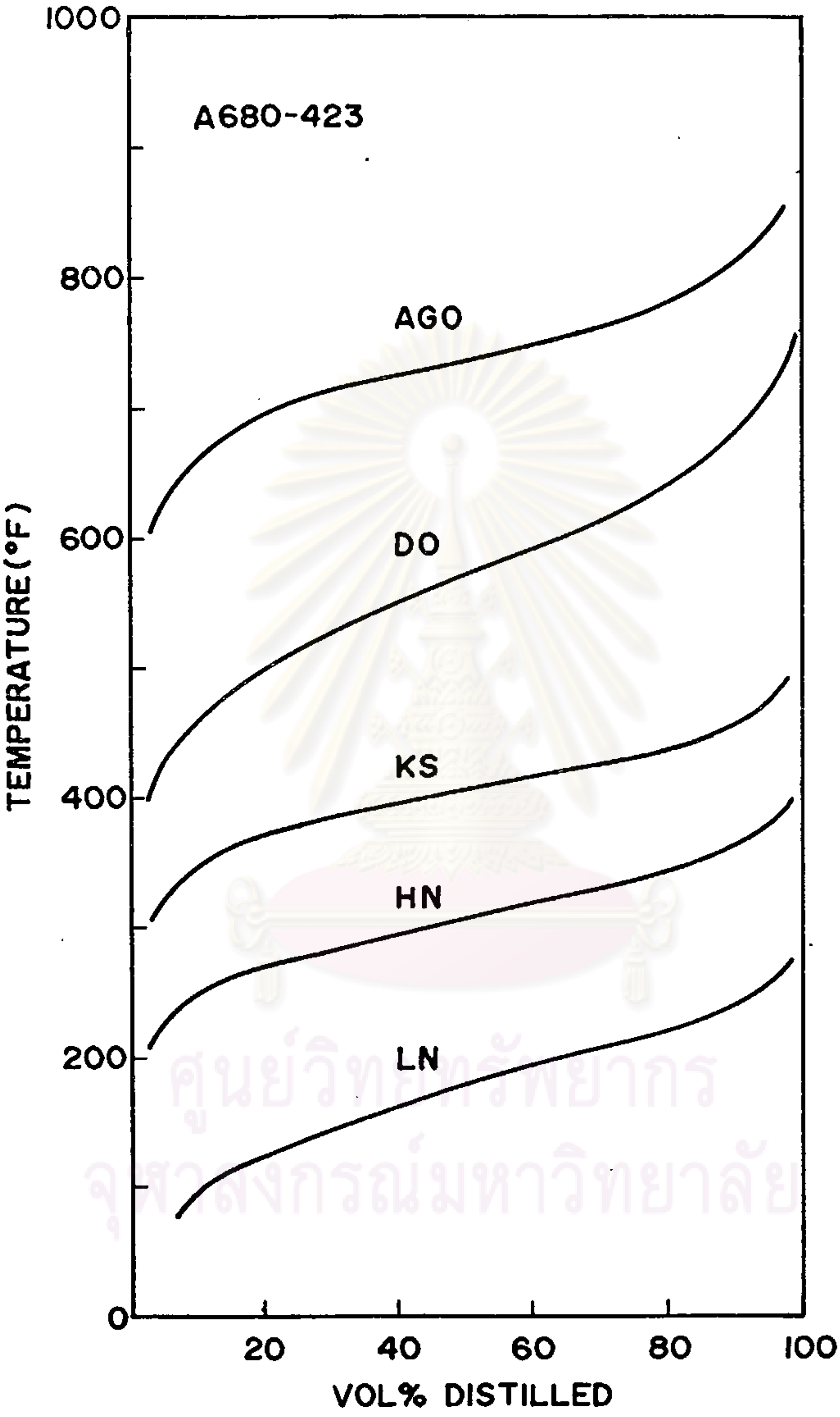

A680-423
AGO
DO
KS
HN
LN
TEMPERATURE (°F)
1000
800
600
400
200
0
20
40
60
80
100
VOL% DISTILLED

Fig.33m

Table 24 ASTM distillation data of products obtained

Run no.	Product	ASTM distillation						
		IP	10%	30%	50%	70%	90%	EP
A600-423	LSR naphtha	71	101	123	139	153	176	206
	HSR naphtha	184	216	240	256	272	296	328
	Kerosene	266	300	325	342	359	384	418
	Diesel Oil	340	401	446	476	507	551	612
	Gas Oil	474	531	572	600	628	669	725
A600-470	LSR naphtha	73	110	133	149	164	187	218
	HSR naphtha	203	232	253	267	281	302	330
	Kerosene	289	320	342	357	372	394	425
	Diesel Oil	347	412	458	490	523	569	634
	Gas Oil	489	547	590	619	648	690	711
A600-517	LSR naphtha	73	105	129	145	162	188	222
	HSR naphtha	198	230	253	269	285	308	340
	Kerosene	278	313	339	356	374	399	435
	Diesel Oil	350	417	466	499	532	581	648
	Gas Oil	491	555	601	633	664	710	774
A620-423	LSR naphtha	80	112	135	152	168	191	224
	HSR naphtha	198	230	253	269	285	309	341
	Kerosene	284	317	341	357	374	398	431
	Diesel Oil	352	416	463	494	526	573	637
	Gas Oil	486	545	588	618	648	691	750

Table 24 (continue)

Run no.	Product	ASTM distillation						
		IP	10%	30%	50%	70%	90%	EP
A620-470	LSR naphtha	79	114	139	157	174	199	234
	HSR naphtha	203	235	259	275	291	314	346
	Kerosene	282	318	344	361	380	405	440
	Diesel Oil	361	426	472	504	536	583	648
	Gas Oil	505	565	609	639	669	713	774
A620-517	LSR naphtha	79	116	143	161	180	207	244
	HSR naphtha	207	240	264	281	297	321	355
	Kerosene	290	326	352	370	388	414	450
	Diesel Oil	362	433	484	518	554	604	674
	Gas Oil	516	579	625	656	688	733	796
A640-423	LSR naphtha	79	115	142	159	177	203	239
	HSR naphtha	212	243	265	280	295	317	348
	Kerosene	297	329	353	369	385	409	442
	Diesel Oil	371	433	477	508	539	583	645
	Gas Oil	515	572	614	642	670	712	769
A640-470	LSR naphtha	85	120	145	163	180	206	241
	HSR naphtha	217	248	270	286	301	324	354
	Kerosene	301	334	359	375	392	416	450
	Diesel Oil	373	440	489	522	556	605	672
	Gas Oil	522	582	626	656	686	729	789

Table 24 (continue)

Run no.	Product	ASTM distillation						
		IP	10%	30%	50%	70%	90%	EP
A640-517	LSR naphtha	85	121	149	167	186	213	250
	HSR naphtha	220	252	276	291	307	331	363
	Kerosene	305	339	364	381	398	423	457
	Diesel Oil	380	448	497	531	564	614	681
	Gas Oil	532	597	643	675	707	754	818
A660-423	LSR naphtha	85	121	147	164	182	208	244
	HSR naphtha	220	251	273	289	304	326	357
	Kerosene	305	338	361	378	394	418	451
	Diesel Oil	377	443	491	524	557	605	671
	Gas Oil	532	589	631	659	688	729	786
A660-470	LSR naphtha	90	125	151	169	186	212	247
	HSR naphtha	224	256	280	296	311	335	367
	Kerosene	308	343	368	386	403	428	463
	Diesel Oil	383	454	505	540	575	626	696
	Gas Oil	538	599	644	674	705	749	810
A660-517	LSR naphtha	70	110	139	159	179	209	249
	HSR naphtha	228	261	284	300	316	339	371
	Kerosene	312	348	373	391	408	434	470
	Diesel Oil	390	461	512	547	582	633	704
	Gas Oil	546	609	656	687	719	765	829

Table 24 (continue)

Run no.	Product	ASTM distillation						
		IP	10%	30%	50%	70%	90%	EP
A680-423	LSR naphtha	90	126	151	169	187	213	250
	HSR naphtha	228	258	281	296	311	334	364
	Kerosene	311	345	370	386	403	428	462
	Diesel Oil	393	456	502	534	566	612	675
	Gas Oil	542	602	645	674	704	747	806

Table 25 Costs of energy and sale prices of products used

Fuel cost (crude heating)	124.252	Bht/MMBtu
Cooling duty cost (accumulator,condenser)	6.68	Bht/MMBtu
LSR naphtha (top stream)	13.833	Bht/gal (3.655 Bht/l)
Reduced crude (bottom stream)	7.173	Bht/gal (1.895 Bht/l)

the change in the sale values of the LSR naphtha and reduced crude compared to the present condition. Thus the objective function can be written in the following form,

Objective function = Product sale values - Operating costs

Table 25 lists the costs of energy and sale prices of products used in calculating the operating costs and the sale values shown in Tables 26-28.

As obviously seen in Table 28, the result of run no. A620-423 yields the highest overall profit among the others. That means the obtained optimum one in the feasible operating condition investigated is 620 F for crude feed temperature and 2.364 for molal reflux ratio. Its corresponding product quality has been shown in Fig. 33d and Table 24.

It should be noted the optimum operation thus obtained was based on the assumption of fixed sidestream production rates. In practice, the production rate of each sidestream product should also be varied according to the ever-changing market supply and demand as well as sale prices.

Table 26 Summary of hourly operating costs

Run no.	Crude heater			Cooling duty				
	Duty (MMBtu)	Deviation (MMBtu)	Cost (Bht)	Accumulator (MMBtu)	Condenser (MMBtu)	Total (MMBtu)	Deviation (MMBtu)	Cost (Bht)
A620-423	56.047	-14.045	-1021.80	32.883	9.007	41.890	-12.368	-82.62
A620-470	56.047	-14.045	-1021.80	32.113	10.242	42.355	-11.903	-79.51
A620-517	56.047	-14.045	-1021.80	31.392	11.426	42.818	-11.440	-76.42
A640-423	63.040	-7.052	-513.04	36.744	10.914	47.658	-6.600	-44.09
A640-470	63.040	-7.052	-513.04	35.871	12.276	48.147	-6.111	-40.82
A640-517	63.040	-7.052	-513.04	35.038	13.582	48.620	-5.638	-37.66
A660-423	70.092	0.0	0.0	40.883	12.194	53.007	-1.181	-7.89
A660-470	70.092	0.0	0.0	39.888	14.370	54.258	0.0	0.0
A660-517	70.092	0.0	0.0	38.932	15.809	54.741	0.483	3.23
A680-423	77.200	7.108	517.15	45.033	14.756	59.789	5.531	36.95

Table 27 Summary of hourly product sale values

Run no.	LSR naphtha				Reduced crude			
	lb mol/h	Deviation (lb mol/h)	Deviation (gal/h)	Sale value (Bht)	lb mol/h	Deviation (lb mol/h)	Deviation (gal/h)	Sale value (Bht)
A620-423	455.09	-168.39	-2752.3	-38071.77	494.81	112.12	6566.0	47095.18
A620-470	501.78	-121.71	-1989.2	-27516.42	466.88	84.20	4930.7	35365.89
A620-517	539.28	-84.21	-1376.3	-19038.14	441.80	59.12	3462.0	24831.24
A640-423	524.84	-98.65	-1612.3	-22302.85	450.72	68.03	3884.0	28575.72
A640-470	565.79	-57.70	-943.0	-13044.57	422.92	40.24	2356.3	16900.57
A640-517	601.46	-22.03	-360.0	-4980.03	398.30	15.62	914.6	6560.15
A660-423	564.71	-58.77	-960.5	-13286.93	409.95	27.26	1596.5	11450.86
A660-470	623.48	0.0	0.0	0.0	382.68	0.0	0.0	0.0
A660-517	657.68	34.20	558.9	7731.06	358.34	-24.38	-1427.8	-10241.00
A680-423	633.52	10.04	164.1	2269.92	374.60	-8.09	-473.8	-3398.21

Table 28 Summary of yearly economic evaluation*

Run no.	Operating costs (MMBht)	Sale value (MMBht)	Overall profit (MMBht)
A620-423	-8.75	71.46	80.21
A620-470	-8.72	62.17	70.89
A620-517	-8.70	45.88	54.58
A640-423	-4.41	49.68	54.09
A640-470	-4.39	30.54	34.93
A640-517	-4.36	12.51	16.87
A660-423	-0.06	-14.54	-14.48
A660-470	0.00	0.00	0.00
A660-517	0.02	-19.88	-19.90
A680-423	4.39	-8.94	-13.32

* 330 days x 24 hours operation