

Temperature-gradient calendering

ABSTRACT

A new calendering technique, temperature-gradient calendering, is described, wherein the paper web is calendered in a single nip formed by two very hot (210°C) iron rolls. The paper contacts the rolls only in the nip, and during this brief contact, the surface fibers are selectively heated, plasticized, and compressed, while the middle of the web remains cool, resilient, and bulky. The surface, printing, and strength properties of laboratory temperature-gradient calendered newsprint are compared with those of conventionally calendered newsprint. When calendered to the same bulk, the temperature-gradient calendered paper is smoother, much glossier, requires less ink to achieve a desired print density, and has somewhat higher strength.

KEYWORDS

Calenders
Nip
Temperature gradient
Surface properties
Newsprint
Heating
Rolls

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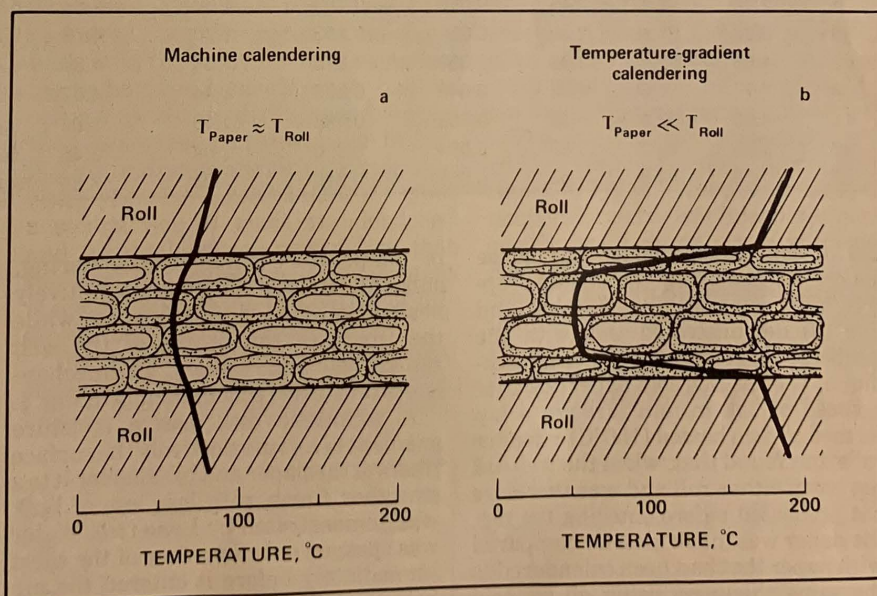
For paper calendered in conventional machine calenders, there exist relationships between the surface properties and the bulk (thickness divided by basis weight) that are significantly influenced not by the calendering conditions but rather by the furnish properties and by the large changes in the basis weight. These relationships, particularly the ones between smoothness (Bekk) or roughness (Bendtsen, Sheffield, Parker Print-Surf) and bulk, have been well documented (1-5), and they apply also for supercalendered papers (3, 5).

The relationships between the surface properties and the bulk impose serious limitations on the machine-calendering operation. A smooth finish can only be achieved by calendering the paper to a lower bulk. When this is done, small-scale basis weight irregularities (formation) will become bulk variations, which are seen as print mottle when the paper is printed. If the paper moisture level is raised to improve the bulk reduction and the development of the desired surface properties, calender blackening (the formation of transparent spots) becomes a problem. To minimize these effects, paper requiring high finish is usually made from a more expensive, slower draining furnish, which improves formation and aids bulk reduction in the calender but also lowers the machine speed and reduces production. The reason for the existence of these relationships may be explained as follows: although paper is not a perfect

elastic solid (6, 7), it can be assumed that any compression or shear forces applied at the surface will be transmitted uniformly throughout its thickness. If there are no major variations in the rheological properties in the thickness direction, the paper will deform

uniformly throughout its thickness, and hence the deformation of the surface fibers will be related to the average deformation in the bulk of the sheet.

Outside the realm of conventional calendering practice, it is possible to alter selectively the rheological proper-



1. Temperature profiles (shown schematically) through the thickness of a paper web passing through calender nip. (a) In machine calenders, the temperature difference between the calender rolls and the paper is generally small, as is the temperature variation through the thickness of the web. When the web is compressed, it deforms uniformly throughout its thickness. (b) In temperature-gradient calendering, the cold web is contacted with the very hot calender rolls, causing high temperature gradients between the surfaces and the middle of the web. When the web is compressed, the hotter surface fibers are deformed more than the cooler fibers in the middle of the web.

I. Calendering conditions, physical and surface properties

Sample no.	No. of nips	Maximum nip load, kN/m	Thickness, μm	Basis weight, g/m^2	Bulk, cm^3/g	Sheffield roughness, ml/min	S10 Print-Surf roughness, μm	75° Hunter gloss, %	Visual efficiency, %	ISO brightness, %
Conventionally calendered newsprint										
1	0	0	108	48.7	2.22	266	6.24	6.2	59.0	47.7
2	1	18	102	48.2	2.12	228	5.74	6.6	59.1	48.4
3	2	35	93	48.0	1.94	168	4.98	7.6	59.1	48.6
4	3	53	85	47.5	1.79	136	4.48	8.6	59.0	47.9
5	4	70	81	47.6	1.70	198	3.96	10.1	58.9	47.9
6	5	88	77	47.8	1.61	94	3.64	1.10	58.8	48.4
7	6	105	74	47.8	1.55	88	3.42	12.0	58.8	47.6
8	7	123	70	47.7	1.47	74	3.15	13.0	58.5	48.0
Temperature-gradient calendered newsprint										
1	0	0	111	49.0	2.26	265	...	6.2	58.9	...
2	1	18	98	48.4	2.02	196	5.04	12.9	58.3	47.5
3	1	35	91	48.3	1.88	150	4.38	16.6	58.1	47.9
4	1	53	85	48.1	1.77	122	3.94	19.4	57.8	47.0
5	1	70	77	48.1	1.60	96	3.44	22.7	57.8	46.8
6	1	88	77	48.0	1.60	92	3.38	23.4	57.3	46.8
7	1	100	77	48.7	1.58	89	3.30	23.8	57.1	46.2

II. Printing and strength properties of calendered newsprint

Sample no.	Bulk, cm^3/g	Ink transfer at 5 g/m^2 , %	Ink requirement, g/m^2	Print-through	Set-off	Burst index, $\text{kPa} \cdot \text{m}^2/\text{g}$	Tear index, $\text{mN} \cdot \text{m}^2/\text{g}$		Breaking length, km		Stretch, %	
							MD	CD	MD	CD	MD	CD
Conventionally calendered newsprint												
1	2.22	50.5	2.50	0.052	0.110	1.16	4.67	6.91	5.35	2.13	1.32	2.07
2	2.12	51.5	2.48	0.048	0.118	1.68	4.64	6.68	5.38	2.11	1.39	2.07
3	1.94	54.8	2.25	0.054	0.120	1.66	4.46	6.57	4.81	1.99	1.25	1.99
4	1.79	57.3	2.05	0.052	0.153	1.47	4.20	6.21	4.61	1.85	1.17	1.68
5	1.70	58.8	1.93	0.051	0.160	1.30	3.65	5.18	4.20	1.75	1.07	1.61
6	1.61	57.3	1.95	0.052	0.193	1.22	3.60	4.55	3.76	1.79	0.92	1.52
7	1.55	58.5	1.93	0.054	0.225	1.11	3.39	4.12	3.28	1.56	0.83	1.35
8	1.47	58.0	1.80	0.052	0.253	1.07	3.12	3.59	3.28	1.50	0.82	1.27
Temperature-gradient calendered newsprint												
1	2.26	51.3	2.45	0.050	0.103	1.66	4.67	6.91	5.35	2.13	1.32	2.07
2	2.02	57.1	2.10	0.051	0.163	1.70	4.72	6.95	5.60	2.11	1.33	1.84
3	1.88	55.0	1.85	0.050	0.215	1.57	4.37	6.47	4.89	2.09	1.12	1.84
4	1.77	55.5	1.65	0.049	0.275	1.44	4.07	6.23	5.21	1.95	1.21	1.52
5	1.60	52.0	1.53	0.053	0.298	1.18	3.61	5.47	4.76	1.78	1.10	1.42
6	1.60	52.0	1.58	0.054	0.310	1.04	3.46	5.46	4.92	1.68	1.15	1.20
7	1.58	54.8	1.55	0.053	0.310	1.02	3.55	5.32	4.02	1.74	0.86	1.34

ties of the paper surface and cause major deviations from the surface property/bulk relationships. Kerekes and Pye (8) demonstrated this with the temperature-gradient calendering technique. They passed cold paper (23°C) at a speed of 336 m/min through a nip formed by two heated (150°C) calender rolls and found that, when the web did not wrap either roll and was therefore not preheated before entering the nip, the paper was much glossier compared with paper that had been calendered to the same thickness using either cold rolls or using hot rolls with one roll wrapped by the web. Kerekes (9) subsequently showed that the heat transferred from the rolls to the paper in the nip could penetrate only the surface of the paper before the web reached the zone of maximum compression. Thus,

in temperature-gradient calendering, only the surface fibers are selectively heated, softened, and deformed, while the fibers in the center of the web remain cold and resilient. The mechanism is illustrated schematically in Fig. 1.

A technique that uses a moisture gradient to soften selectively the surface fibers of the paper and to calender it to a smoother finish with less loss of bulk was demonstrated by Lyne (10). Water was sprayed onto a surface of the sheet immediately before it entered the nip between two hot (130°C) calender rolls. The spray was positioned so close to the nip that water did not have time to penetrate the web; only the surface fibers were moistened as the paper entered the nip.

In this report, the temperature-gradient calendering technique, which has

now been studied in greater detail, is presented. Separate lots of the same uncalendered newsprint were calendered in a laboratory calender by conventional calendering and also by temperature-gradient calendering. A range of sheet bulks was obtained, and this served as the basis for comparison of surface, printing, and strength properties.

Results

Samples were taken immediately after calendering and conditioned for at least 24 hr at 23°C and 50% RH before testing. The physical, surface, and printing properties are listed in Tables I and II. The two-sidedness of paper can be affected in the calendering operation, particularly with temperature-gradient

calendering. However, this was not of primary interest in this study. Therefore, only averages of the top-side and bottom-side measurements of surface and printing properties are reported.

The Parker Print-Surf roughness measurements (11) were made with a soft backing (a neoprene litho blanket, 85° Shore A hardness) and two levels of pressure on the land area (1000 kPa for S10 and 2000 kPa for S20). Print tests were performed on a GFL press, using the procedure outlined in standards SCAN P35:72 and SCAN P35:77 and described by Crotofino (5). All printing properties are reported as averages of the top-side and bottom-side values. Ink requirement, print-through, and set-off were evaluated at a print density of 0.85. The strength properties are also listed in Table II and were determined by CPPA standard methods.

Discussion

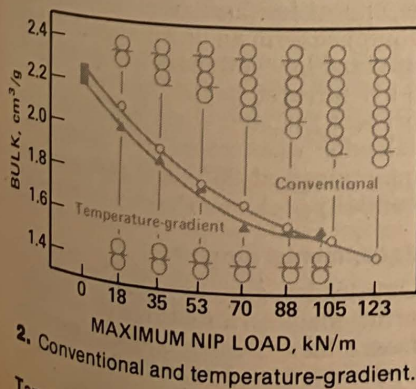
Bulk

The bulk of the papers calendered by the two techniques is shown in Fig. 2 as a function of the maximum nip load to which the paper had been subjected. The bulk values of the temperature-gradient calendered papers, which were calendered in a single nip, appear to be similar to those achieved in multiple nips by the conventional techniques. These results indicate clearly, as did the results of Kerekes and Pye (8), that single-nip calendering of newsprint is feasible, in principle, when very hot calender rolls are used.

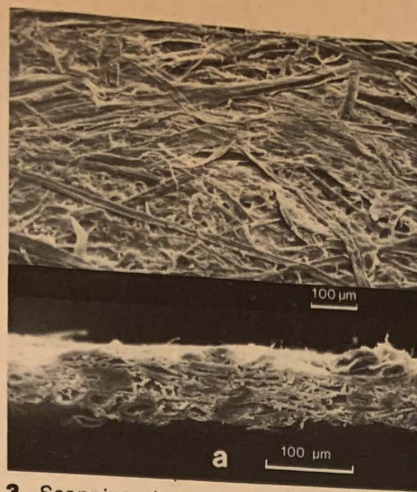
For the subsequent discussion of the surface, printing, and strength properties, bulk is used, as a basis for comparison, to represent the severity of calendering. This choice was made because no single calendering parameter can adequately represent the severity of calendering, particularly in a comparison of two different calendering techniques. Furthermore, bulk, unlike roughness or printability, can be measured by a simple, well-established method.

Micrographs

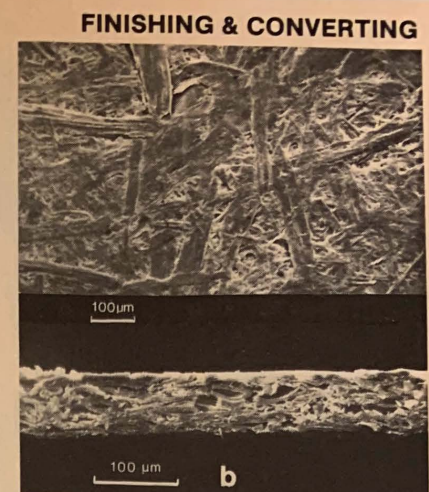
Scanning electron micrographs of the bottom sides and cross sections of two samples, which were calendered to a



2. Conventional and temperature-gradient.



3. Scanning electron micrographs of the bottom side (top photo) and the cross section (bottom photo) of newsprint calendered to a bulk of 1.6 cm³/g by (a) conventional calendering, (b) temperature-gradient calendering.

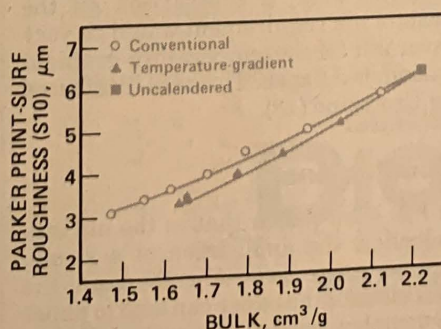


bulk of approximately 1.6 cm³/g with the conventional and the temperature-gradient techniques, are shown in Fig. 3. These pictures of the temperature-gradient calendered paper appear smooth and fused, while the surface of the conventionally calendered paper shows collapsed and uncollapsed fibers throughout its structure, and there is no obvious bulk or density gradient through the thickness of the sheet. The cross section of the temperature-gradient calendered paper, on the other hand, shows completely collapsed fibers at the surface and uncollapsed fibers in the middle. This paper is obviously more dense at the surface than in the middle.

Surface properties

The average Sheffield roughness of the samples, when compared at the same bulk, was the same for both calendering techniques. Hence it is not possible, using this test, to distinguish between the two surface textures shown in Fig. 3. This finding confirms the conclusion reached earlier by the author (5), from a comparison of machine-calendered and supercalendered newsprints, that the Sheffield roughness measurement is unsuitable for the evaluation of different calendering techniques.

The Parker Print-Surf roughness, shown in Fig. 4, distinguishes clearly between the two calendering tech-

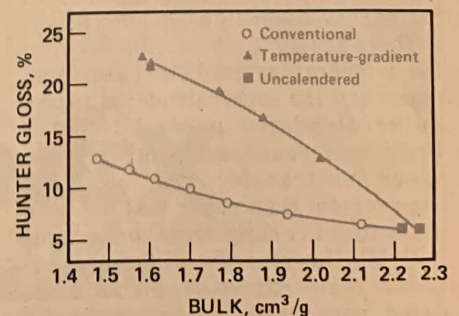


4. Parker Print-Surf roughness (S10).

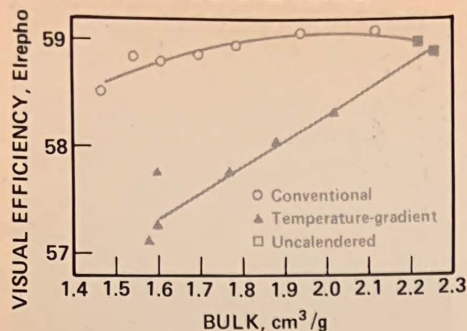
niques. At all levels of bulk, the temperature-gradient calendered paper is smoother (i.e., has a lower roughness) than the conventionally calendered paper.

The surface property that was most dramatically influenced by the difference in calendering techniques was the 75° Hunter gloss, which is shown in Fig. 5. The temperature-gradient technique produced a very much higher gloss than the conventional calendering technique, indicating that small-scale roughness was reduced substantially by the high roll-surface temperatures. The gloss produced with the temperature-gradient technique is much higher than that produced even by supercalenders. From Fig. 5 it can be seen that newsprint that was temperature-gradient calendered to 1.6 cm³/g bulk reached a gloss of 23%. To obtain this gloss with a supercalender, the newsprint would have to be calendered to a low bulk of approximately 1.3 cm³/g (5).

The visual efficiency measured with an Elrepho photometer (Filter no. 10) is shown in Fig. 6. At the same bulk, the temperature-gradient calendered paper clearly has a lower visual efficiency. Some of the difference in visual efficiency can be attributed to the substantially higher gloss of the temperature-gradient calendered paper (12). Similar differences were also observed in the ISO brightness shown in Table I.



5. 75° Hunter gloss as a function of bulk.



6. Visual efficiency as a function of bulk.

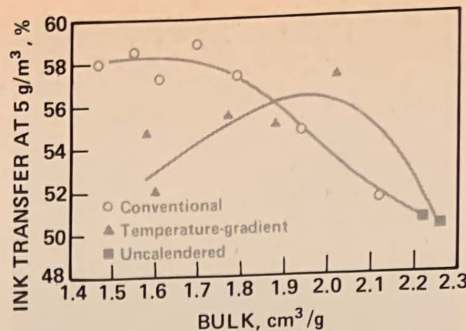
Printing properties

The ink transfer to the paper from a plate inked to a level of 5 g/m^2 is shown in Fig. 7. At high bulk, the temperature-gradient calendered paper showed a higher ink transfer than the conventionally calendered paper, but for lower bulk values, the trend was reversed. Ink transfer is affected by two factors: the contact between the paper and the printing plate, and the ability of the paper to accept the ink. Uncalendered paper is very bulky and rough and makes poor contact with the printing plate. As the bulk and roughness of the paper are decreased with calendering, the contact improves and the ink transfer increases. However, with increased calendering, the porosity of the surface and the ability of the surface to accept ink decrease.

At the same bulk, although the temperature-gradient calendered paper is smoother than the conventionally calendered paper, it seems that the increase in ink transfer resulting from increased smoothness (and better contact with the printing plate) is offset by the decrease in ink transfer attributed to lower surface porosity. Therefore, for newsprint with bulk of commercial interest (i.e., less than $1.6 \text{ cm}^3/\text{g}$), the temperature-gradient calendered paper showed a substantially lower ink transfer.

The ink requirement for a print density of 0.85, shown in Fig. 8, was consistently lower for the temperature-gradient calendered paper. The difference in density or density gradients through the thickness of the sheet appears to have had no influence on the print-through. In spite of the lower ink requirement, the set-off (Table II) is considerably higher for the temperature-gradient calendered paper than for the conventionally calendered paper.

There are some similarities between the temperature-gradient calendered paper and the supercalendered paper. Supercalendered paper has lower Print-Surf roughness, higher gloss, lower ink transfer, and lower ink requirement than paper that has been conventionally calendered to the same bulk (5). However, the differences between temperature-gradient calendered paper and the conventionally calendered papers are much more pronounced,



7. Percent ink as a function of bulk.

particularly for gloss. The properties of temperature-gradient calendered paper are also very similar to those reported by Lyne (10) for the moisture-gradient calendered paper.

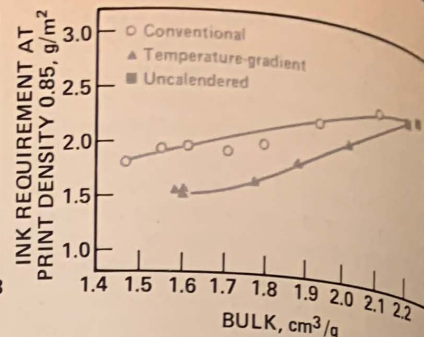
Strength properties

The tear index, breaking length, stretch, and burst strength were reduced as the paper was calendered to a lower bulk by either of the two calendering methods. At the same bulk, the reductions in MD tear index, CD breaking length, MD stretch, and burst strength are similar for the two methods. However, the CD tear index and the MD breaking length were higher and the CD stretch slightly lower for the temperature-gradient calendered paper. With two exceptions, these findings are in agreement with those of Kerekes and Pye (8). Kerekes and Pye found no difference in CD stretch, but they did find that the burst factor of their temperature-gradient calendered papers was somewhat higher than that of the conventionally calendered paper at the same sheet thickness.

It may be argued that, for the purpose of comparing strength properties, bulk is not an appropriate basis. Since it is the printing properties of the newsprint that are of primary interest, it may be preferable to compare different papers at equivalent levels of some appropriate measure of printability rather than at the same level of bulk. If we calendered the newsprint to a desired level of ink requirement, for example, we would have to calender it to a much lower bulk using the conventional method than we would using the temperature-gradient technique. Since the strength properties considered here decrease with decreasing bulk, a comparison on the basis of ink requirement would be very favorable for the temperature-gradient calendered paper. This was illustrated by Crotofino (13).

Conclusions

It has been shown that in the nip of a calender, the application of a strong temperature gradient through the thickness of the paper can lead to paper properties that are distinctly different from those obtained for paper calen-



8. Ink requirement for a print density of 0.85.

dered to the same bulk with conventional techniques. The temperature-gradient calendered paper was found to have:

- lower Parker Print-Surf roughness
- very much higher 75° Hunter gloss
- lower visual efficiency
- lower ink transfer
- lower ink requirement
- higher set-off

When the strength properties of temperature-gradient calendered paper were compared with those of conventionally calendered paper at the same bulk, the temperature-gradient calendered paper was found to have:

- higher CD tear index
- higher MD breaking length
- slightly lower CD stretch

No significant difference was found for the other strength properties when compared at the same level of bulk. However, compared at the same level of ink requirement, all strength properties were higher for the temperature-gradient calendered paper.

Experimental

Equipment

The experiments were performed using the Institute's laboratory calender (8). This calender had three chromium-plated steel rolls, each 200 mm diameter and 360 mm wide. Nip loads up to 105 kN/m could be applied independently to each nip, and each roll could be heated electrically to surface temperatures in excess of 200°C . The center roll was driven by a variable speed drive to a maximum speed of 730 m/min at full load. The calender was equipped with an unwind and a wind-up stand for continuous web feeding. A 6-kW infrared heater was installed to preheat the web when required. The calender was located in a laboratory maintained at 23°C and 50% relative humidity.

Experimental program

Uncalendered western Canadian newsprint, made on a fourdrinier machine from a furnish containing 49% groundwood, 32% TMP, and 19% semi-bleached

kraft pulp, was used. The calendering was carried out at a speed of 300 m/min under the conditions outlined in the following paragraphs. Before calendering, the paper was conditioned by rewinding it slowly.

Conventional calendering. For the simulation of conventional calendering, the web was preheated by passing it underneath the infrared heater and around two calender rolls that were heated to approximately 70°C and 50°C, respectively. The temperature of the web entering the upper nip was adjusted to 50 (±3)°C by adjusting the power to the infrared heater. The paper was calendered only in the upper nip; the lower nip was not loaded. The web was calendered by successive passes through the nip with loads of 18, 35, 53, 88, 105, and 123 kN/m. After each pass, samples were taken for testing, and the remainder of the paper was reconditioned before the next pass by rewinding it slowly.

Temperature-gradient calendering. For the temperature-gradient calendering, the paper, having a temperature of 23°C, entered the nip between the top and the center rolls and was calendered in one pass. The rolls were heated to a temperature of 210 (±10)°C, and nip loads of 18, 35, 53, 70, 88, and 100 kN/m were applied.

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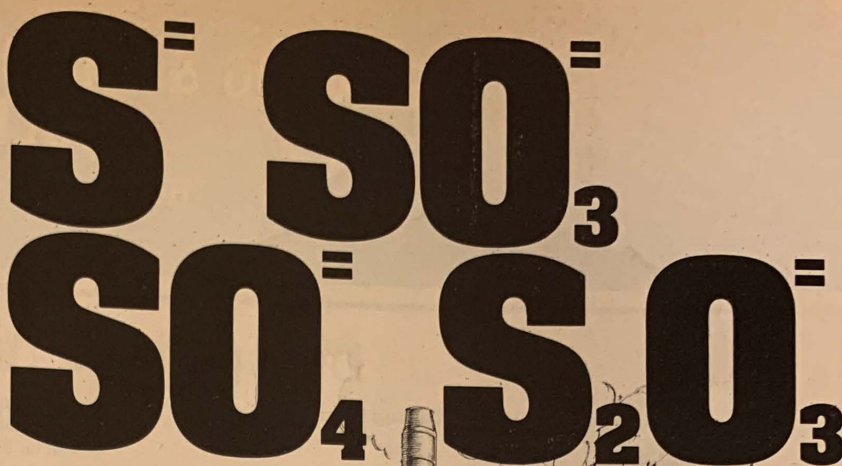
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